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INTERIM TECHNICAL REPORT

NORSAR PHASE 2

THE 1968 INSTALLATION PROGRAM

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26 November 1969

INTERIM TECHNICAL REPORT

NORSAR (NORWEGIAN SEISMIC ARRAY)

PHASE 2

THE 1968 INSTALLATION PROGRAM

NORWEGIAN DEFENCE
RESEARCH ESTABLISHMENT
N2007 KJELLER - NORWAY
INTERN RAPPORT S-45

This research project has been sponsored under the technical direction of the HQ ELECTRONIC SYSTEMS DIVISION (AFSC) through the European Office of Aerospace Research, OAR, United States Air Force, and is under the over all direction of the Advanced Research Projects Agency.

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Project Supervisor	:	F Lied, Director NDRE
Project Leader	:	Ø Brandtzæg, Major, NDRE
Title of Contract	:	"Norwegian Seismic System, Phase 2"

FOREWORD

This research installation project is sponsored and supported by the Advanced Research Projects Agency of the Department of Defense. Technical guidance and direction for Contract No F61052-68-C-0060 has been provided by the Electronics System Division (AFSC). Contractual support was provided by the European Office of Aerospace Research, OAR, This report covers the period from 1 January through December 1968.

We wish to acknowledge the very considerable support and assistance provided during the course of this project by the Nuclear Test Detection Office (ARPA), the Seismic Array Program Office (ESD), the European Office of Aerospace Research (EOAR), the Seismic Array Analysis Center (SAAC) of IBM and the Education and Technical Services Division of the Philco-Ford Corporation.

This technical report has been reviewed and is approved.

Nicholas A. Orsini

Nicholas A Orsini, Lt Col USAF
Field Program Manager
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NORSAR (NORWEGIAN SEISMIC ARRAY), PHASE 2 - THE 1968 INSTALLATION PROGRAM

ABSTRACT

The Phase 1 installations of project NORSAR (Norwegian Seismic Array) provided only one of the many subarrays of the large seismic array. Phase 2, which covers the planning and installation needed to complete the whole array, therefore constitutes a major part (some 90%) of the total effort.

The size of the task necessitated that the work be spread over two working seasons, i e 1968 and 1969 installation programs. This interim report covers the development of the large array configuration and the planning and installation of the 1968 program.

1 INTRODUCTION

1.1 General status of the NORSAR project per January 1968

At the turn of the year 1967/68, when the bulk of the NORSAR Phase 1 installations had been completed, very much uncertainty was still attached to the further development of the project.

Project NORSAR in its entirety, comprising Phase 2 as well as Phase 1, was sanctioned in principle by Norwegian authorities already in the summer of 1967, but the formal agreement to Phase 2 of the project awaited the outcome of government-to-government negotiations conducted throughout the winter and spring 1967/68.

The geometrical and technical layouts of the Phase 2 installations were also far from being settled. On the contrary, the 1967 tentative concept, stipulating a large array of 5 to 10 Øyer-like (20 Short Period (SP) sensors) subarrays and one more or less independent hexagonal pattern of Long Period (LP) sensors, was questioned and challenged by widely different ideas.

It was known for a certainty, however, that the Phase 2 volume of work would at any rate exceed that of Phase 1 by an order of magnitude, and that planning in detail had to be ready early in the summer if a reasonable part of the total effort was to be accomplished in 1968. This planning was to include all preparations except signing of the main contract between the Electronic Systems Division (ESD) and the Norwegian Defence Research Establishment (NDRE) as well as the NDRE subcontracts.

1.2 The 1968 installation program

Full re-evaluation of the large array configuration was initiated in January 1968. The finally approved (March) layout had 22 subarrays distributed roughly evenly within a circle of 100 km diameter. Concentric to a central subarray (designated 1A) an inner circle (B-ring) of diameter about 50 km was to contain 7 subarrays, the remaining 14 subarrays (including the Øyer subarray) constituting the outer C-ring. The geometrical and technical size of each subarray was, however, to be considerably less than the Øyer one, viz six SP points and one LP installation co-located with one of the SP points, all within a circle of diameter about 8 - 10 km.

Early plans calling for installation in 1968 of about half of the total Phase 2 work volume, i e 10 to 11 subarrays, soon had to be abandoned in view of the time available. Apart from the time needed for detailed siting and land acquisition, both described in greater detail in the next chapters, the status of the government level negotiations did not indicate an early spring agreement.

As a more realistic goal it was decided to prepare a 1968 installation comprising the central subarray (01A) and those of the B-ring, i e 8 out of 21 subarrays or some 30 - 40% of the total Phase 2 effort.

When the Phase 2 project was formally approved by the Norwegian Government in late May, preparations by the ESD/NDRE and NDRE subcontractors were in the final stage. The effective date of the main contract, covering the whole of Phase 2, eventually turned out to be 1 July 1968.

1.3 Management of the project

As in the case of Phase 1, Phase 2 is basically sponsored and supported by the Advanced Research Project Agency (ARPA) of the US Department of Defense, while the Electronic Systems Division (ESD of AFSC) provides technical guidance and direction to the contractor: The Norwegian Defence Research Establishment, Kjeller, Norway. To meet the need for close technical cooperation, ESD established in July 1968 an Oslo Field Office (ESUH-4), staffed by Lt Col N A Orsini, Field Program Manager, and Capt R A Jedlicka, Technical Adviser.

The size of the task did not allow NDRE to operate in the way that the 1967 conditions had made necessary, viz to deal to a very great extent directly with the subcontractors and cover contract negotiations and guidance as well as control. A firm of consultants had been employed in 1967, but its service potentialities had not been fully utilised.

For the preparation and implementation of the 1968 work, NDRE drew on the services of many firms and institutions, including ESD.

No attempt was made to establish in a formal way a project management organisation with rigid lines of communication and command. The many unknown factors of the installation task required a flow of decisive information to pass in many directions within the system, especially in the beginning. A first requirement was there-

fore a flexible organization that easily could comply with temporary needs for communication channels. On the other hand the control of work progress and the cooperation between the involved parties had to be very tight in order to implement the 1968 construction program before winter and also to release personnel in due time for the planning period of the 1969 program. Figure 1.1 shows the main features of the management organisation as it was developed through experiences during 1968.

A very important management routine was the weekly or fortnightly project meetings held at NDRE throughout most of the period. These regular meetings gathered managerial personnel from ESD, NDRE and consultants, occasionally also other US or Norwegian specialists. They provided an opportunity for status reporting, general exchange of information, discussion of special problems as well as decision-making, and were the main instrument of coordination. Other meetings concerning special topics were held when and where required.

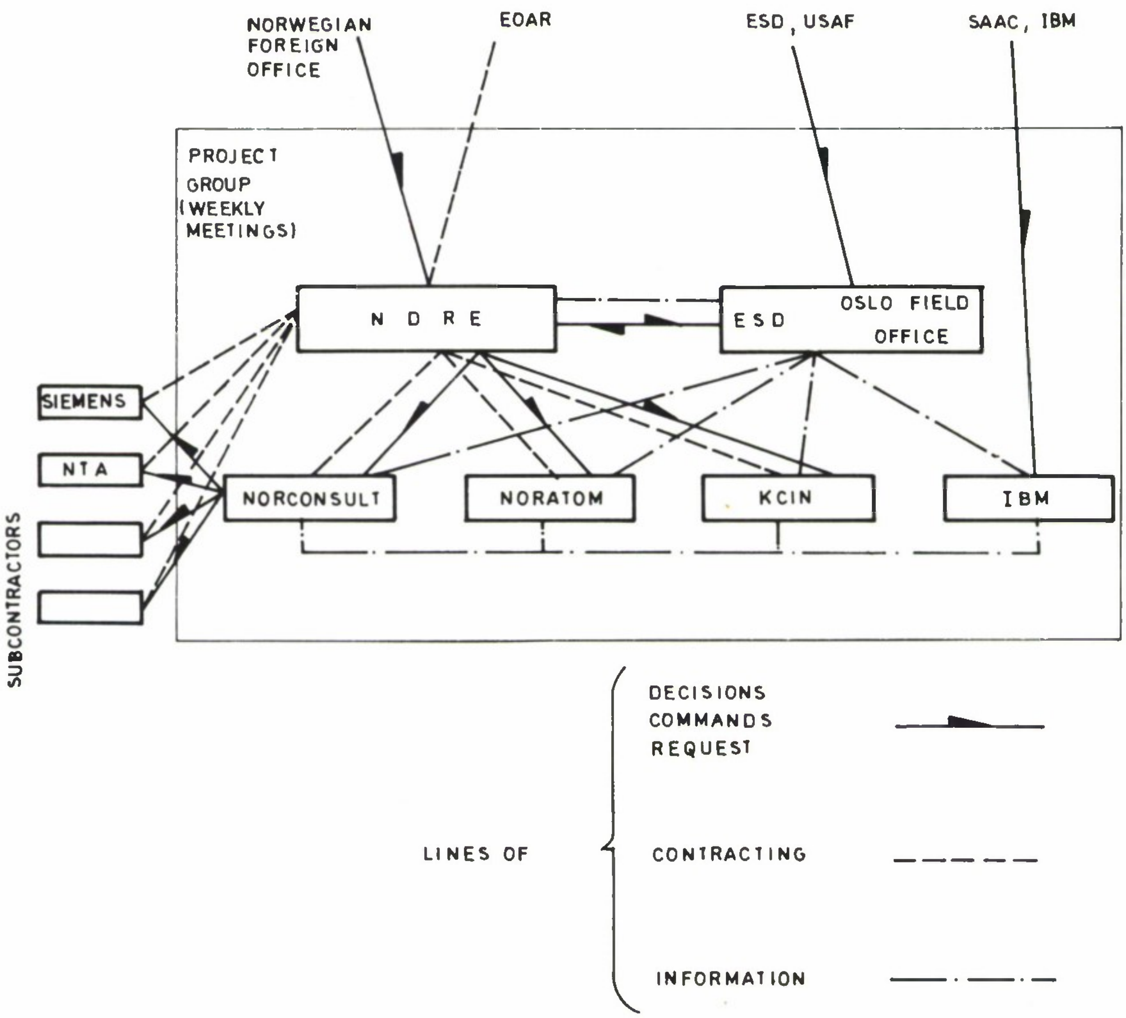


Figure 1.1 Management organisation

2 SITING

In the broadest sense, siting covered all steps from deciding the centroid of the large array to picking the accurate spots for vaults and boreholes, and routes for the interconnecting cables. The results of the Phase 1 system measurements during winter/spring 1967/68 were not contrary to the 1967 plan of locating the larger array in south-eastern Norway, with Lake Mjøsa as the centroid (Figure 2.1). This decision being maintained, the next step was to decide on the overall configuration of the array.

2.1 Development of large array configuration

The basic design objective of the NORSAR system was largely to match the performance of the Montana LASA (Large Aperture Seismic Array) System. In contrast to the LASA LP configuration, the original NORSAR LP system was planned to be an almost completely regular hexagonal system (Figure 2.2). This regular hexagonal system was to have six dominant side lobe directions with the same sensitivity as the main lobe direction, but for directions between the main lobe and the dominant side lobes, the sensitivity was to be very small.

The NORSAR SP system was originally planned to have five (Figure 2.2) or ten subarrays, each with twenty seismometers. These arrays were to be co-located with a selection of five (ten) LP sites. The selection was made on the basis that the terrain of the subarrays should be suitable from geological and land acquisition points of view.

It was realized that a more random pattern than the regular filled hexagon would give a considerable discrimination of the dominant side lobe at the cost of having poorer discrimination in intermediate directions. There is, however, no conclusive agreement in the seismic world about the relative merits of these two schools of thought.

In January 1968 it was decided that directional properties of the array should be re-evaluated. The re-evaluation took place in Washington during February, and one of the conclusions was that a small subarray co-located with each LP site would give a much better performance than a smaller number of larger arrays and that this could be effected within the same cost frame.

Up to January 1968 considerable effort had been put into site selection for the original concept of the array. At that time it became evident through the work done at IBM Seismic Array Analysis Center (SAAC), Washington DC, that the original array configuration had some less desirable properties.

The SP array consisting of five subarrays rather randomly selected from the point of view of directional properties would produce a directional response that suffered from a significant side lobe very close to the main lobe. It was evident that a substantial reduction in side lobes could be achieved with the same number of sensors through better use of the available aperture. The "available aperture" is in this connection to be understood as the area which had to be connected anyway to the

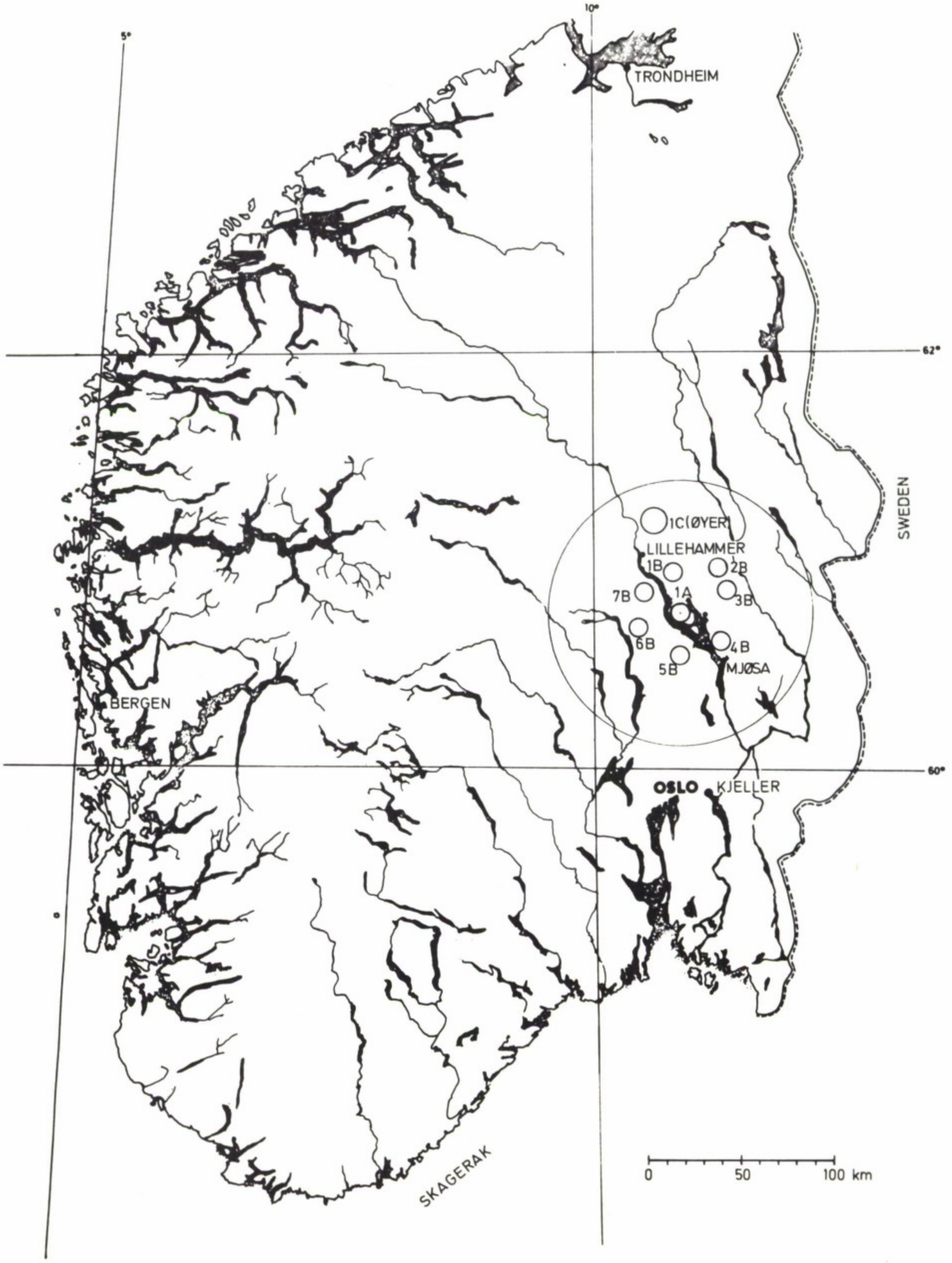


Figure 2.1 Southern Norway
Circle indicates approximate aperture of large seismic array.

communication system in order to take care of the LP system. If, however, the subarrays (centroids) formed a regular hexagonal pattern, there would still be a considerable side lobe close to the main lobe for the SP system.

Simulation of randomly distributed and heptagonal pattern models on a computer showed that the heptagonal pattern with deviations superimposed (Figure 2. 3) could produce beam patterns that had the closest side lobes further removed and lower down than was possible with the hexagonal pattern. It would also be possible to adjust side lobes individually at specific azimuths by calculated displacements of sensor position. This is referred to as a "tuned array". The randomised distribution could also produce a favourable response pattern, but this was more difficult to adjust by sensor displacements.

While these studies were going on in USA, some effort was in Norway put into fitting the original hexagonal LP pattern to the idea of distributed small SP arrays instead of five large ones. Since the final decision was to implement the heptagonal pattern, no use could be made of this work.

A procedure had been devised in Washington to keep a step-by-step record of inevitable adjustments to proposed configurations, and of predicting new locations for the remaining sensor locations in a way that still kept the array directional pattern optimised, but the time factor prevented this method being followed. A greater bulk of planning had to be incorporated between each review. The 1968 construction program had at that time been cut down from twelve to eight subarrays, i e the center subarray plus the seven subarrays of the inner "heptagon" (B-ring). One of the basically heptagonal patterns, modified in map studies by terrain, geology etc, but not optimised for pattern properties, was selected. Relative to this starting point, the detailed staking resulted in several deviations. After a major part of these adjustments had been made in the field, the coordinates were submitted for recalculation of pattern properties. The conclusion of these calculations was that the SP locations should be kept as staked, but the LP locations could be moved to other positions with advantage.

By limiting relocation to interchange of SP and LP positions, it was possible to incorporate these late changes in the 1968 program. An incidental advantage of these shifts was a reduction in the cost of providing power and communication to the LP sites. At a still later stage the LP sites of subarrays 2B and 3B had to be relocated, the first because of excessive cost of providing power, the second because no suitable bedrock could be found at reasonable depth.

For the planning of the 1969 building program a revised C-ring based on pattern calculation was used as the basis. These calculations were based on the real sites of the A and B subarrays and the new sites of the C-ring, adjusted relative to the original pattern.

As the planning time was limited due to the approaching winter, and in view of the fact that still further relocations might be required from pattern considerations, only six of the remaining subarrays were picked out for field siting and staking. These six were picked from the consideration that three of them should be suitable

Figure 2. 2 Original NORSAR configuration concept
Large circles - Øyer-like SP subarrays
Small circles - LP installations

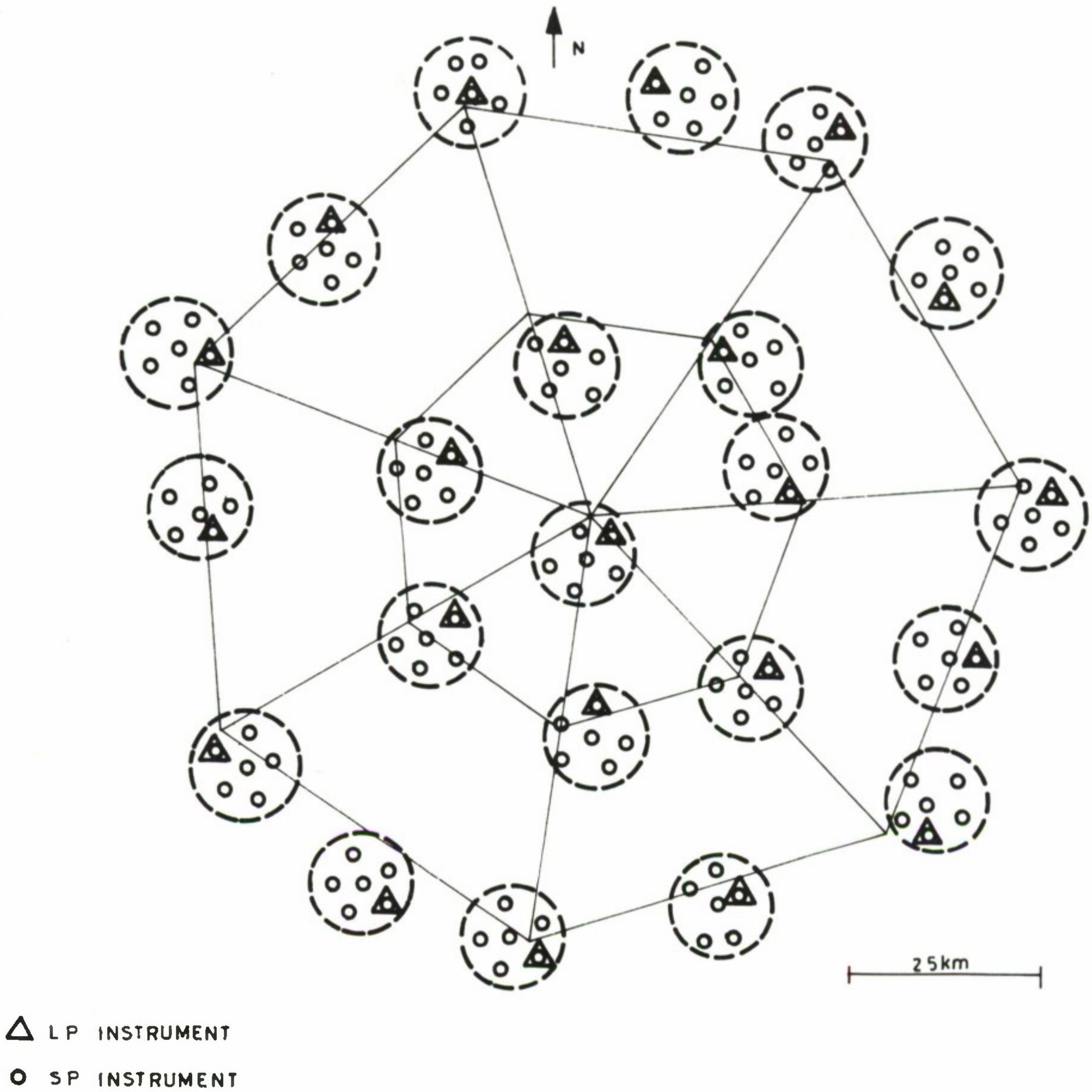


Figure 2.3 Heptagonal pattern, randomised
Circles - subarrays

for an early start of construction in 1969, the remaining three were sites where the construction season was likely to start very late.

The staking of these six arrays (02C, 03C, 04C, 07C, 08C and 10C) again led to significant deviations from the configuration that the computer had predicted as most favourable, and a 2.5 dB deterioration of the closest side lobe resulted. By readjusting the position of the remaining seven arrays it proved possible to recover most of this loss. The final staking of the remaining seven did not materially alter the array properties.

Figure 2.4 shows the final configuration of the A and B-ring subarrays, and also the existing 01C subarray at Øyer.

The following reports provided guidelines for the large-scale siting:

- NORSAR Array Design, preliminary report from SAAC, IBM Corp, dated 6 March 1968
- Fifth Quarterly Technical Report, Experimental Signal Processing System, ESD report TR-68-450, February 1968

2.2 Sites requirements

The configuration of sensor locations within each subarray area has in principle been based on a pattern of a circle with five segments of 15° each as angular limitation and an inner and outer circle of 4 and 5 km respectively as radial limitations. The central location had a circular limitation of 1 km diameter. This pattern (Figure 2.5) was stipulated in a documentation provided by ESD in April 1968, together with the following notes:

a) One short period instrument shall be collocated at the Central Terminal Vault with a Three Component Long Period Instrument.

b) One shaded area shall be assigned the location specified in Note 1.

c) Five additional Short Period Instruments shall be located in the five remaining shaded areas in accordance with local conditions.

d) Subarray azimuth shall be selected to facilitate the placement of the instrument in the terrain.

These requirements were received after the first part of the siting had been started, based on a similar pattern with five segments of 15° each but with a radial limitation of three circles with 3, 4 and 5 km respectively (Figure 2.6). The 3 and 5 km circles were the absolute inner and outer limitations with the 4 km circle as the ideal. The minimum distance between stations was limited to 3 km.

Another factor that influenced the initial siting was the decision that every seismometer should be placed in "long holes" drilled into the ground. Surface holes (short holes) had still not been considered. During the siting operations great importance was attached to finding sites with reasonable access. In remote areas suitable landing places for helicopters had to be considered.

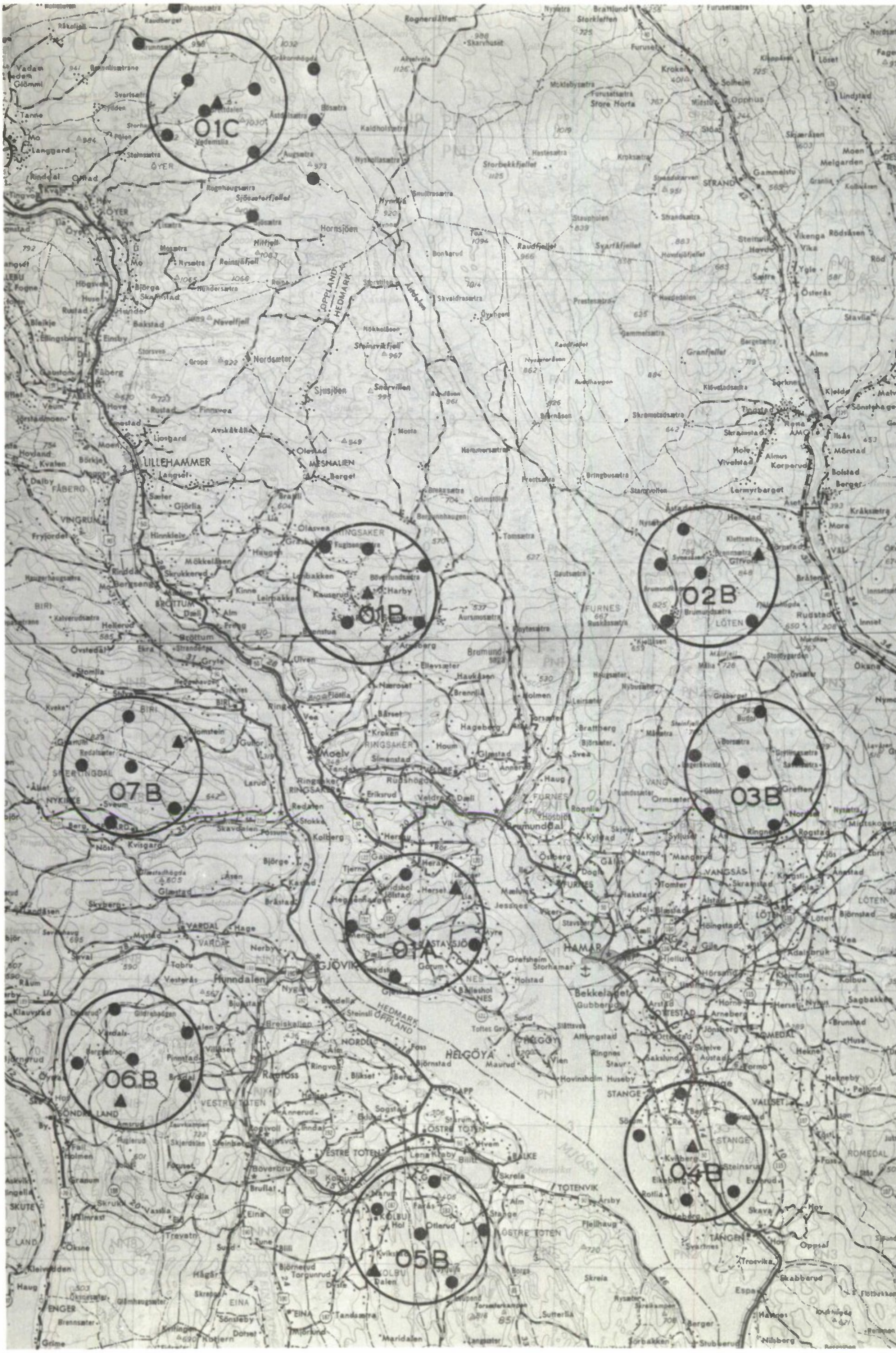


Figure 2.4 Configuration of the 1968 (and 1967) program field installations

Circle - subarray
Round dot - single SP instrument
Triangular dot - location of subarray central area with LP installation and SP seismometers in LP vault and in 60 m deep borehole

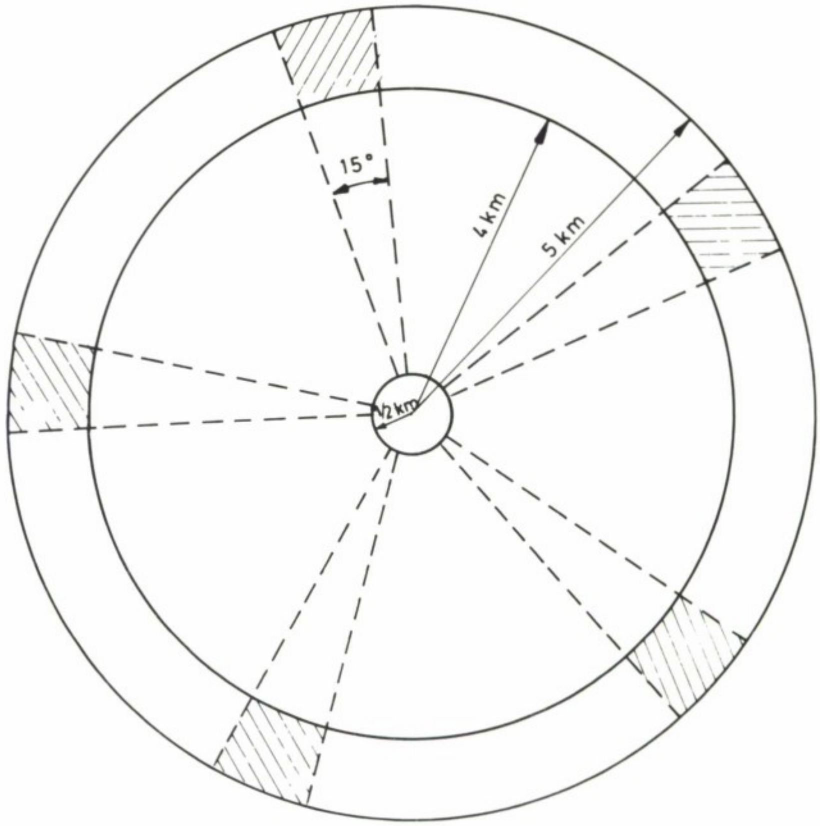


Figure 2.5 Spatial restrictions within the subarray, final pattern

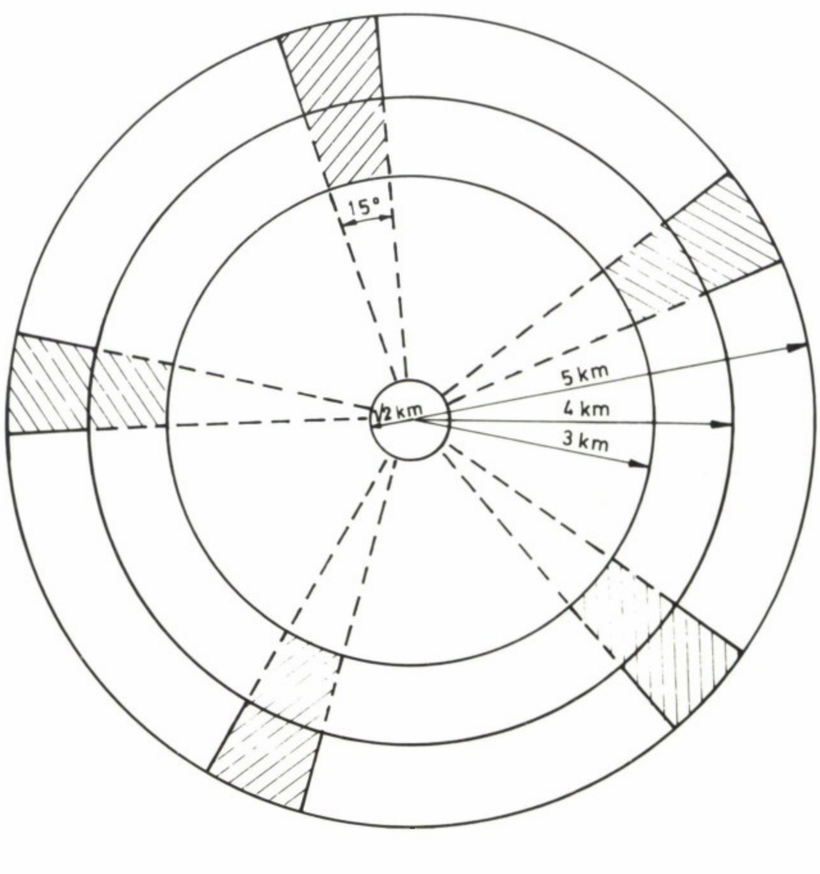


Figure 2.6 Spatial restrictions within the subarray, interim pattern

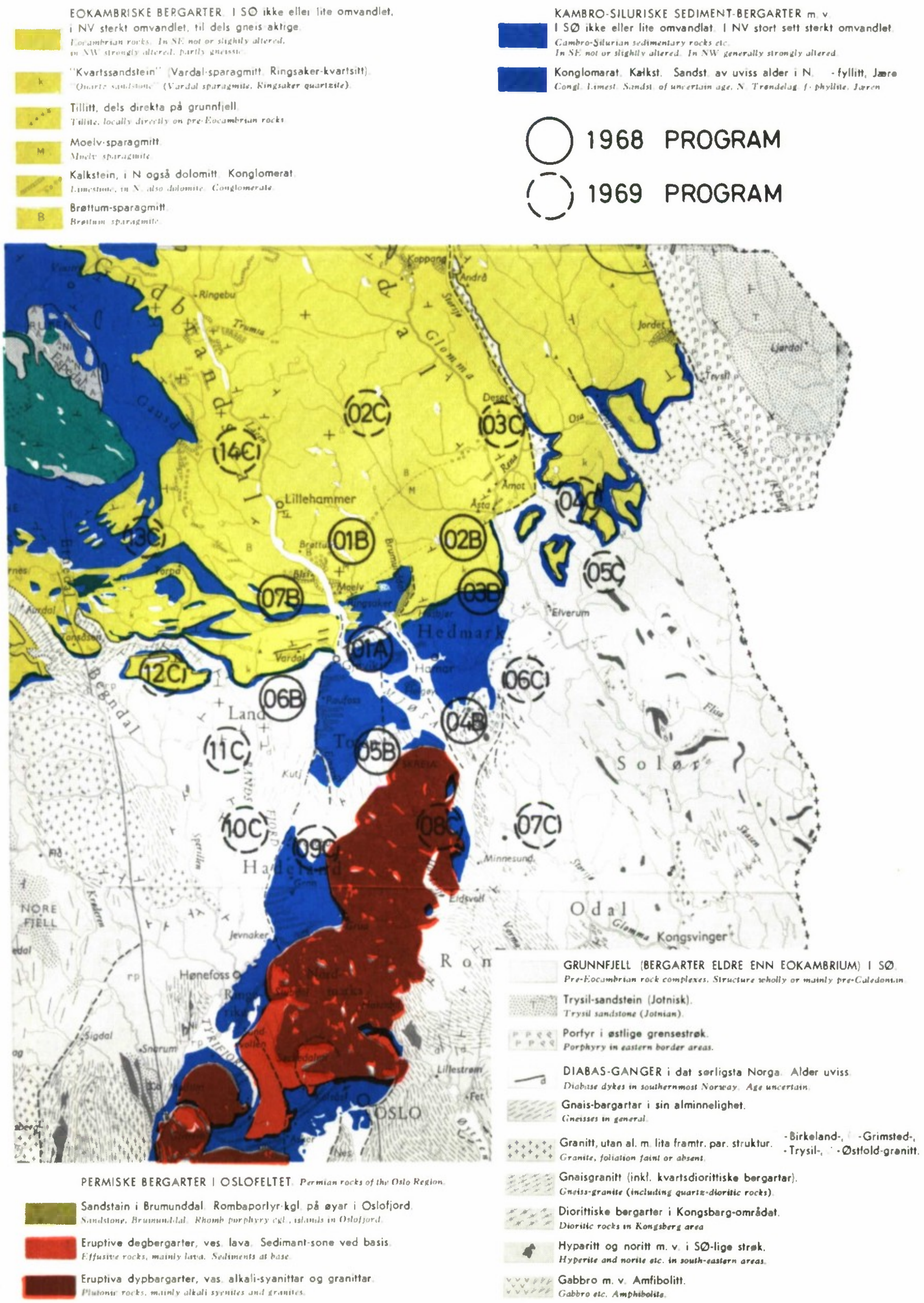


Figure 2.7 Bedrock geology, south-eastern Norway

When the modified and final siting criteria were presented, a great number of sites had already been staked in the terrain and negotiations with the landowners had started.

It was considered too late to start relocations and the result was that a few seismometer locations do not fully comply with the revised criteria.

In addition to reasonable accessibility, the following siting criteria were used:

a) The sites should preferably be selected in areas with rock outcrops.

b) Disturbances from roads, railways, rivers and farms should be avoided.

c) Wind noise from single trees, power lines, and mountain peaks should be avoided.

d) A minimum number of land owners should be involved.

e) The LP vault foundation should be on solid rock, have good drainage and reasonable distances to access road, telephone and power networks.

f) The following minimum distances from noise sources were used:
   1000 m from railways, highways and big rivers
   150 m from secondary roads
   25 m from forest roads and small farm roads

No constraints were laid down as to the nature of the geological large-scale bedrock formations, but on the local scale the geologist ensured that holes were drilled/ blasted and LP vaults placed in solid rock without excessive cracking.

Figure 2. 7 shows the bedrock geology of the various subarrays.

Throughout all phases, from setting up criteria to actual field work, siting was guided and/or assisted by US advisers, in particular from SAAC (IBM) and the Oslo Field Office of the ESD.

2.3 Detailed siting

The detailed siting was based on a modified heptagonal array according to a list of coordinates (Table 2. 1) received from IBM. A preliminary siting was then carried out by means of air photographs and geological and topographical maps. During this operation seismic points were picked out as close as possible to the listed coordinates, taking into consideration the above siting criteria. At the same time an area was indicated for each selected point to reserve alternative locations if still another adjustment of the pattern was called for. A new list of coordinates was worked out according to this procedure and forwarded to IBM. New coordinates were returned indicating the desired changes.

Field siting started at the end of May 1968, as soon as the snow had melted. The terrain around each point selected from air photographs was visited and surveyed and the most favourable site was staked by means of a 2. 5 m aluminium stake with an orange painted sign on top. A siting report was prepared for each site, describing the topography, geology, type of rock, overburden, access roads etc. Figures 2. 8 and 2. 9 are examples of siting reports for SP and LP sites, respectively.

Pattern 15

Station	X	Y
01A00	599.500	6747.700
01A01 LP	602.800	6749.900
01A02	602.500	6745.400
01A03	598.500	6743.900
01A04	595.500	6748.300
01A05	598.500	6751.400
01B00	596.100	6768.000
01B01 LP	596.600	6771.100
01B02	599.700	6769.900
01B03	599.850	6764.700
01B04	594.650	6765.300
01B05	593.100	6770.500
02B00	620.100	6769.200
02B01	623.000	6770.900
02B02	623.100	6765.850
02B03	617.900	6765.200
02B04 LP	615.600	6769.250
02B05	618.800	6772.650
03B00	623.750	6755.800
03B01	624.200	6759.700
03B02	627.600	6756.400
03B03 LP	625.700	6752.400
03B04	620.900	6752.900
03B05	620.000	6757.550
04B00	620.000	6728.500
04B01	622.900	6730.800
04B02	623.300	6726.100
04B03	618.900	6724.500
04B04	616.100	6728.300
04B05 LP	618.600	6732.200
05B00	600.650	6722.200
05B01 LP	601.250	6726.150
05B02	605.300	6721.800
05B03	602.800	6718.600
05B04	597.850	6719.350
05B05	597.800	6724.650
06B00	579.750	6734.200
06B01 LP	582.800	6737.000
06B02	583.300	6732.350
06B03	578.950	6731.200
06B04	575.750	6733.700
06B05	578.200	6737.800
07B00	579.300	6755.000
07B01 LP	582.650	6757.000
07B02	582.300	6752.300
07B03	577.800	6751.250
07B04	575.600	6755.350
07B05	578.550	6758.900

Table 2.1 First approximation coordinates list (UTM)

NORWEGIAN SEISMIC ARRAY - PHASE 2

SITING REPORT

SITE NO: 04B MAP REF. 1916 II Tangen

BOREHOLE NO: 04B04 PHOTO REF: 830 U 2-3

OBSERVATIONS	DATE	FIELD SITING	SIGN.
Coordinates	15/5	x = 616.200 y = 6729.250	PBo
Topographical description		On the border of dense and more scattered wood. Gentle hilly terrain. Water in a ditch 20 m N.	
Type and nature of deposits		Scarcely cover of heather humus and morainic drift.	
Estimated depth to bedrock		1 m. Outcrops close by.	
Estimated ground water level		1 m	
Type and nature of rock		Massive gneiss	
Dip and strike		N 15 E. Dip 60 W	
Cracks and joints			
Nearest road		Private road 80 m NW. Track close by.	
Nearest powerline		300 m E	
Nearest telephone line			
Transportation		Good by tractor 80 m from road.	
Seismical disturbances		Mjøsa 500 m W. The wood.	
Land owner			
General characteristics of site		Good	
Recomandations and proposed site for alternative			
Coordinates			
Approval			
Remarks			

Figure 2.8 Siting report - SP site

NORWEGIAN SEISMIC ARRAY - PHASE 2

SITING REPORT

SITE NO: 03B — MAP REF. 1916 I Løten

LP-STATION NO: 03B02 — PHOTO REF: 830 Æ 37-38

OBSERVATIONS	DATE	FIELD SITING	SIGN.
Coordinates	25/6	x = ~~627.150~~ 626.400 y = 6755.~~850~~ 750	KR
Topographical description		The terrain on the site is sloping towards SW, and is rough with many small hills. The site is cleared for timber. Water in a nearby creek.	
Type and nature of deposits		Probably large amounts of sandy moraine. Some boulders.	
Estimated depth to bedrock		5-10 m	
Estimated ground water level		1-3 m	
Type and nature of rock		Unknown	
Dip and strike		Unknown	
Cracks and joints		Unknown	
Nearest road		Timber-road approx 60 m NW.	
Nearest powerline		About 1.5 km	
Nearest telephone line		Unknown	
Transportation		By car almost to the site.	
Seismical disturbances		The creek	
Land owner		Løten almenning	
General characteristics of site		Questionable because of the large thickness of deposits.	
Recomondations and proposed site for alternative		Seismic soundings are made. Depth to bedrock is 5.5 - 12 m.	
Coordinates			
Approval			
Remarks			

Figure 2.9 Siting report - Central area (LP) site

Already at the start of the siting operations problems were encountered due to deficiency of maps and air photographs. Some of the maps were so old and inaccurate that proper plotting was impossible. The air photographs were in some cases more than 15 years old and especially in forest areas considerable changes had taken place in the meantime, with new planted areas or trees cut down. Also a great number of new forest roads had been constructed. These circumstances caused considerable difficulties in locating the sites, and in some areas the transportation possibilities proved difficult, making relocation of some sensors necessary.

During later siting operations helicopters were used, and this proved to be a good help. The transportation was much quicker, and the siting crew was also able to survey the terrain by flying over the potential sites. Much time was saved and the siting team was able to pick out suitable locations even in areas which were poorly mapped or not photographed at all.

The resulting coordinates are given in Table 2. 2. Maps of the subarrays are presented in Figures 2. 10 through 2. 17.

2. 3. 1 LPV/CTV sites

The selection of each of the LPV and CTV sites caused considerably more work than siting of the SP points. In addition to the general criteria for avoiding noise sources, the siting crew had to consider the transportation possibilities and to ensure that the LPVs could be founded on solid rock. The drainage had also to be considered, but generally this caused no severe problems.

It was not possible to fulfil all the criteria that were laid down without relocating some of the sites in relation to the original pattern.

Having large areas covered with thick overburden, the array 03B turned out to be particularly difficult. It was at one stage proposed to move the LPV from 03B03 to 03B05, which was the only place in the area with outcrops of rock. However, this could not be done because of the high costs of the power supply and its effect on the pattern properties, and seismic sounding had to be carried out in order to find areas where the depth to bedrock was not excessive. This proved to be difficult, but an acceptable place was finally selected. The seismic soundings were complemented by test drillings. Even these investigations were not entirely reliable; a hard stony moraine was once mistaken for bedrock.

The locations of the LP sites were changed several times in order to find a satisfactory combination of the conditions of the overburden, reasonable cost of the power supply and acceptable pattern properties.

2. 3. 2 SP-sites

The siting criteria were somewhat changed when it was decided that the SP instruments preferably should be placed in shallow holes blasted in surface rock. The siting was then simplified since it was no longer necessary to let the drill rig transportation cost dominate the selection.

Site	Cartesian		UTM system zone 32		Altitude in meters above sea level
	°North	°East	x	y	
01A00	60°49'25".4467	10°49'56".5011	6 744 705.346	599 649.573	379.000
01A01	60°50'39".2139	10°53'11".5139	6 747 070.597	602 529.342	426.399
01A11	60°50'38".8475	10°53'11".7930	6 747 059.386	602 533.881	425.690
01A02	60°48'20".5901	10°53'49".7203	6 742 799.352	603 230.033	362.500
01A03	60°47'17".3003	10°48'30".1957	6 740 705.282	598 455.289	223.195
01A04	60°48'37".8626	10°45'45".1532	6 743 129.410	595 892.790	297.374
01A05	60°51'02".4496	10°49'09".4332	6 747 686.106	598 855.445	290.869
01B00	61° 1'50".7686	10°46'38".6370	6 767 678.391	596 035.769	529.980
01B10	61° 1'50".2052	10°46'39".3379	6 767 661.247	596 046.761	524.010
01B01	61° 3'41".6050	10°47' 0".1365	6 771 115.748	596 264.986	596.960
01B02	61° 2'57".1350	10°51'24".9994	6 769 850.580	600 274.704	521.360
01B03	61° 0'46".6372	10°50'13".4160	6 765 783.572	599 314.426	429.860
01B04	61° 0'43".0092	10°45' 8".7000	6 765 545.944	594 742.249	398.557
01B05	61° 3'34".9711	10°43'18".8895	6 770 821.714	592 953.498	553.443
02B00	61° 2'23".0531	11°12'53".0995	6 769 397.297	619 627.121	717.924
02B01	61° 2'58".2816	11°17'38".0171	6 770 634.062	623 862.598	613.920
02B11	61° 2'58".8628	11°17'37".6300	6 770 651.834	623 856.164	614.110
02B02	61° 0'24".9597	11°16'40".0994	6 765 861.688	623 159.147	647.950
02B03	61° 0'38".6472	11°10' 3".7824	6 766 083.009	617 194.300	730.910
02B04	61° 2'59".1637	11° 9'29".1888	6 770 412.024	616 531.628	670.690
02B05	61° 4'15".6969	11°11'51".6295	6 772 850.250	618 588.076	637.030
03B00	60°54'46".7957	11°16'10".5773	6 755 387.395	623 078.274	529.240
03B01	60°57' 8".1710	11°16'33".6650	6 759 771.952	623 274.065	731.640
03B02	60°54'56".9749	11°19'51".1587	6 755 818.818	626 388.871	447.100
03B12	60°54'56".9572	11°19'51".7286	6 755 818.575	626 397.471	447.770
03B03	60°52'37".1660	11°18' 1".9490	6 751 436.725	624 896.180	344.630
03B04	60°53'17".4661	11°13'15".7980	6 752 534.356	620 539.802	464.743
03B05	60°55'29".7447	11°12'32".8454	6 756 603.716	619 754.534	700.508
04B00	60°40'25".7531	11°11'17".2079	6 728 606.187	619 548.393	239.020
04B10	60°40'26".1054	11°11'17".0143	6 728 616.983	619 545.092	236.350
04B01	60°41'20".6502	11°14'59".4654	6 730 417.942	622 862.432	214.610
04B02	60°39' 1".6351	11°15' 2".2381	6 726 119.986	623 051.791	266.813
04B03	60°38'24".1940	11°11' 9".3614	6 724 842.619	619 554.433	253.457
04B04	60°40'51".5063	11° 7'33".3488	6 729 291.168	616 126.039	163.910
04B05	60°42'31".0721	11°10'48".0787	6 732 467.407	618 977.767	242.370
05B00	60°37'20".6141	10°50'12".7562	6 722 291.753	600 522.276	428.993
05B01	60°39'32".6922	10°51'17".5765	6 726 404.783	601 392.138	231.926
05B02	60°37'20".4314	10°55'39".6527	6 722 428.384	605 490.734	379.405
05B03	60°35'19".8492	10°52'31".8755	6 718 616.079	602 743.250	553.745
05B04	60°35'46".1879	10°46'45".7102	6 719 284.402	597 454.506	444.804
05B14	60°35'46".7088	10°46'45".7066	6 719 300.514	597 454.015	442.074
05B05	60°37'56".1236	10°46'37".0956	6 723 300.027	597 214.821	375.784
06B00	60°43'48".1278	10°27'32".1219	6 733 760.942	579 575.342	630.410
06B01	60°45'19".6419	10°31'47".8266	6 736 680.046	583 383.110	447.235
06B02	60°42'54".4478	10°31'21".7813	6 732 179.362	583 093.015	588.630
06B03	60°41'54".8110	10°26'08".8603	6 730 227.673	578 390.611	505.758
06B13	60°41'54".5127	10°26'09".2101	6 730 218.560	578 396.117	503.138
06B04	60°43'54".9120	10°23'25".7891	6 733 889.848	575.839.081	471.820
06B05	60°46'21".1877	10°25'52".5552	6 738 462.699	577 963.742	554.925
07B00	60°55'11".9951	10°27'56".8184	6 754 924.962	579 476.817	759.719
07B01	60°56'29".4167	10°31'46".5550	6 757 399.081	582 880.672	506.595
07B11	60°56'28".9423	10°31'45".9315	6 757 384.186	582 871.631	505.175
07B02	60°53'52".3833	10°31'20".0618	6 752 531.912	582 594.786	601.367
07B03	60°53'06".3318	10°25'00".1245	6 750 978.925	576 899.841	451.793
07B04	60°55'26".5335	10°23'36".6793	6 755 289.276	575 549.586	717.609
07B05	60°57'10".9518	10°27'35".3345	6 758 597.772	579 071.300	564.279

Table 2.2 Final coordinates of the seismic points in the A and B-ring subarrays

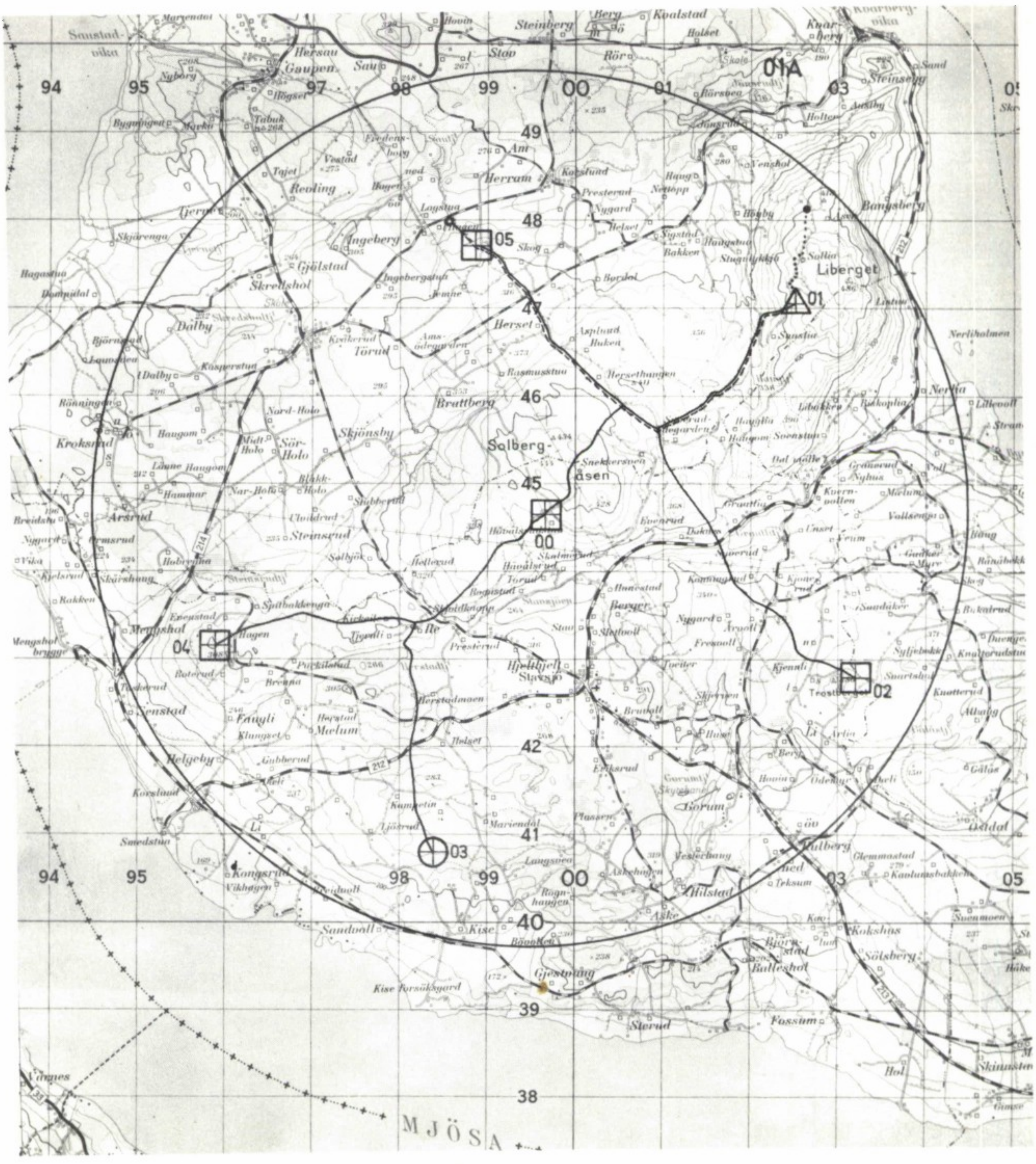


Figure 2.10 Subarray 01A, final configuration

Central area (LP) site △
Shallow (blasted) SP hole □
Deep (drilled) SP hole ○

Cable trench
Power line
Telephone/data link

Figure 2.11 <u>Subarray 01B, final configuration</u>

Central area (LP) site	△	Cable trench	———
Shallow (blasted) SP hole	□	Power line	·······●
Deep (drilled) SP hole	○	Telephone/data link	- - - - ○

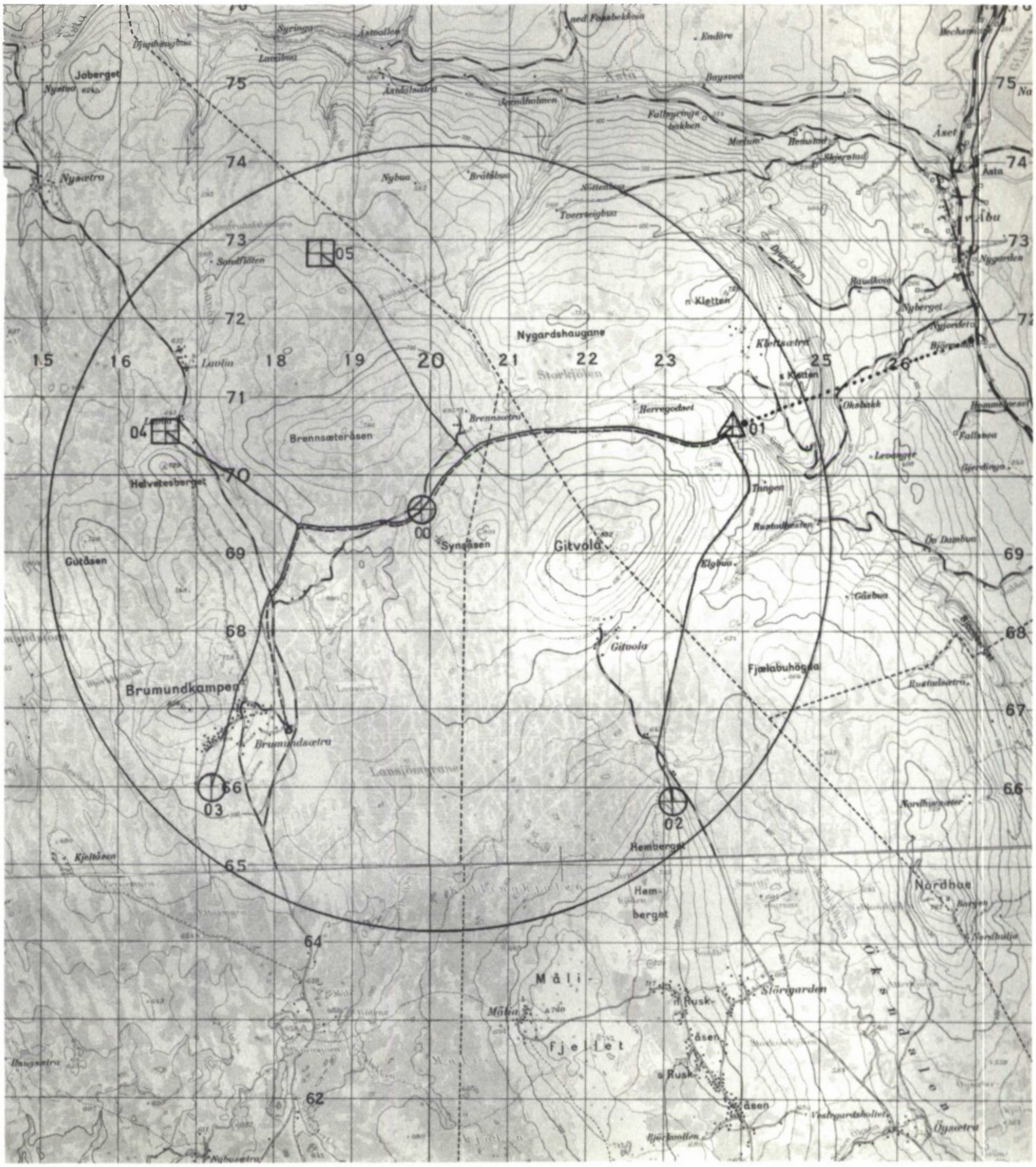


Figure 2.12 Subarray 02B, final configuration

Central area (LP) site	△	Cable trench	———
Shallow (blasted) SP hole	□	Power line	••••••●
Deep (drilled) SP hole	○	Telephone/data link	– – –o

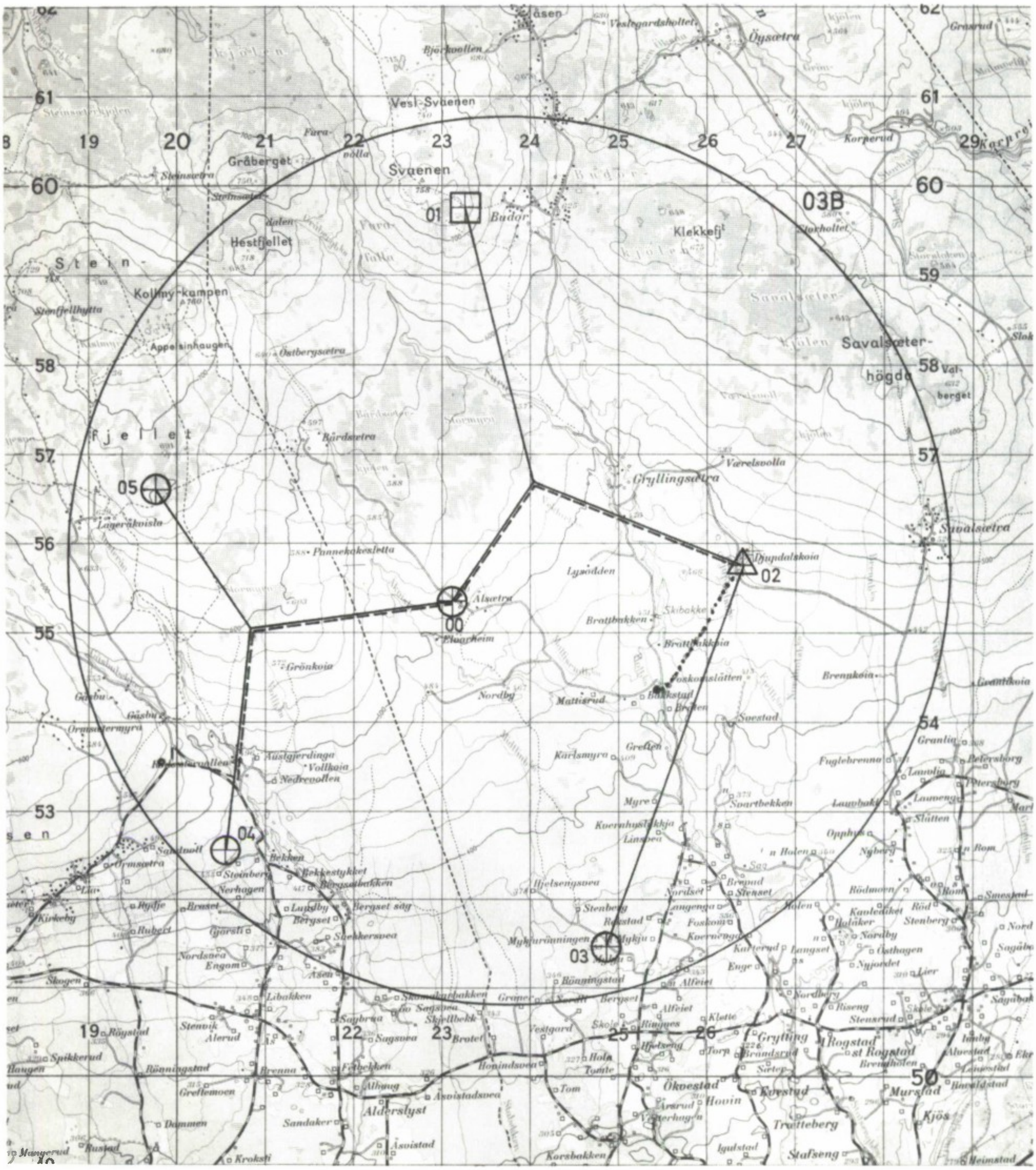


Figure 2.13 <u>Subarray 03B, final configuration</u>

Central area (LP) site	△	Cable trench	———
Shallow (blasted) SP hole	□	Power line	••••••●
Deep (drilled) SP hole	○	Telephone/data link	---○

Figure 2.14 Subarray 04B, final configuration

Central area (LP) site	△	Cable trench	———
Shallow (blasted) SP hole	□	Power line	......●
Deep (drilled) SP hole	○	Telephone/data link	----o

Figure 2.15 Subarray 05B, final configuration

Central area (LP) site	△	Cable trench	———
Shallow (blasted) SP hole	□	Power line	······●
Deep (drilled) SP hole	○	Telephone/data link	----o

Figure 2.16 Subarray 06B, final configuration

Central area (LP) site	△	Cable trench	———
Shallow (blasted) SP hole	□	Power line	······●
Deep (drilled) SP hole	○	Telephone/data link	----o

Figure 2.17 Subarray 07B, final configuration

Central area (LP) site	△	Cable trench	———
Shallow (blasted) SP hole	□	Power line	••••••●
Deep (drilled) SP hole	○	Telephone/data link	----o

Only when the extent and depth of overburden left no choice was the seismometer hole made by drilling through the loose deposits and 1.5 m into solid rock.

2.3.3 60 m holes

The subarray layout specifications stipulated that all the A and B-ring subarrays should be fitted with a 60 m deep borehole to enable further seismic noise studies. The 60 m holes were not subject to any specific siting as they were supposed to be placed within 10 m of the previously sited LPVs. The staking was performed in close cooperation with the contractor in order to find the best place for the drill-rig, easy access etc. In general there were no special problems with this type of siting.

2.3.4 General remarks

Decisions on where to blast short holes and where to drill long holes were based on previous studies of air photographs and visual geological observations in the terrain. This proved to be accurate enough except for two sites.

The central CTV/LPV area constitutes by far the most complicated part of the subarray, accommodating vaults with LP instruments and data- and power-handling equipment as well as the SP installation. Local topography, geology and access routes for seismic cables, telephone and power differs much from site to site, making each site layout an individual one. The layout maps of all the A and B-ring subarray central areas are shown in Figures 2.18 through 2.25.

2.3.5 Trench routes

The criteria for the siting of the trench routes were influenced by considerations relating to the landowners, to economic trenching methods and to the mobility of the trenching machinery in the terrain. At the same time rocky areas, cultivated land and valuable forest were to be avoided. Experience showed that the best trenching routes went through bog areas and across open fields in the woods. It was at first proposed that preference should be given to trenching along forest roads and tractor roads, but this was abandoned since the cable's exposure to damage outweighed advantages in the trenching operation.

As a first approximation, straight line schematic routes were marked on a map. In this connection it should be emphasized that it is of considerable economic interest to find the cheapest network interconnecting the subarray points. The simple system of two 6-pair cables starting from the center point out to two SP-points has been chosen to illustrate the problem (Figure 2.26).

If the trench price is g and the cable price k, a common trench costs $2(g/2+k)$, compared with $(g+k)$ for a single trench. The cost of connecting one sensor to the center hole will then be

$$C = (\tfrac{1}{2}g+k)(a \operatorname{cotg}\varphi - a \operatorname{cotg}\alpha) + (g+k)\, a \sec\alpha \quad \text{and}$$

$$C \text{ minimum for } dC/d\alpha = 0 \text{ or } \cos\alpha = (g/2+k)/(g+k)$$

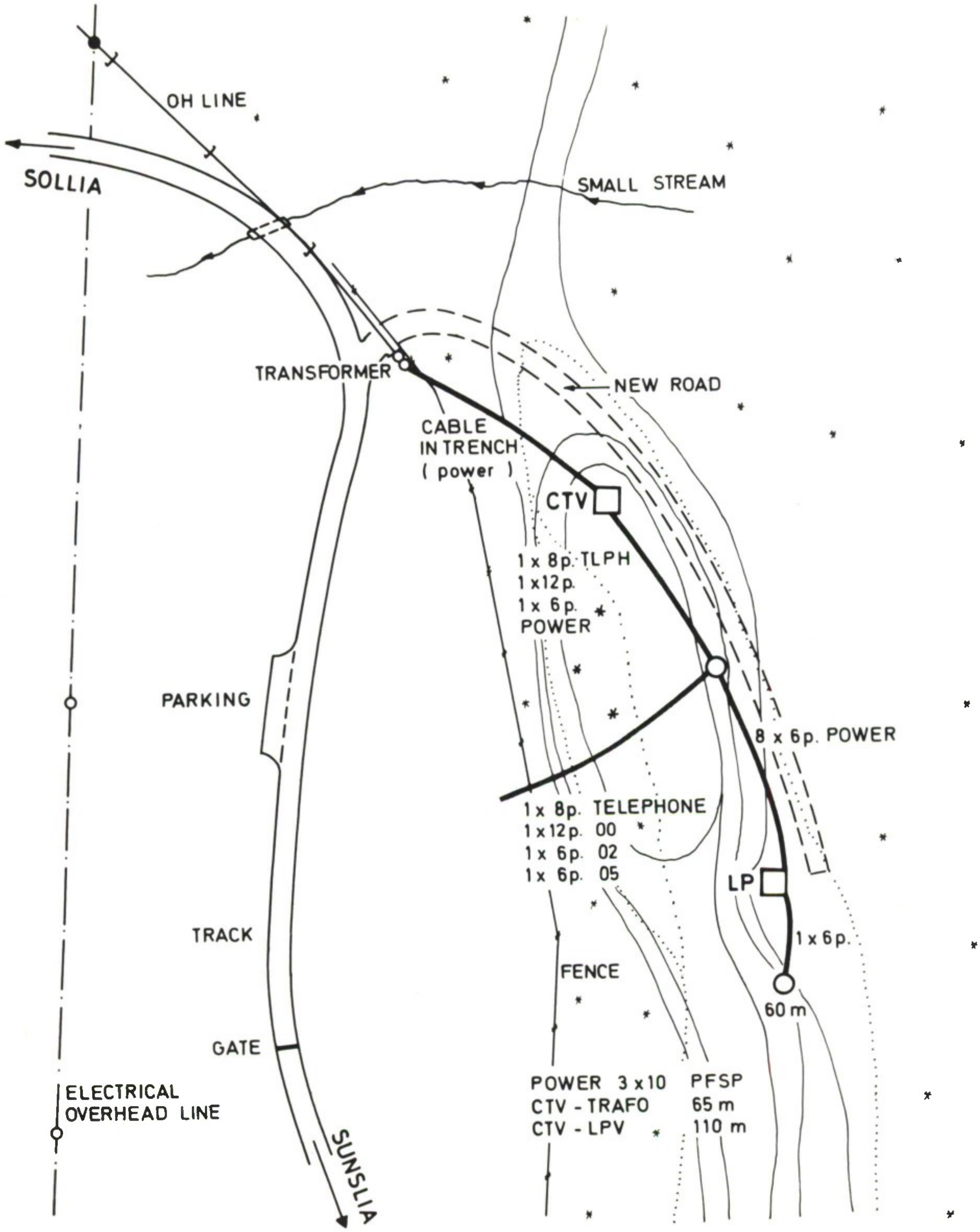


Figure 2.18 Central area, subarray 01A Nes

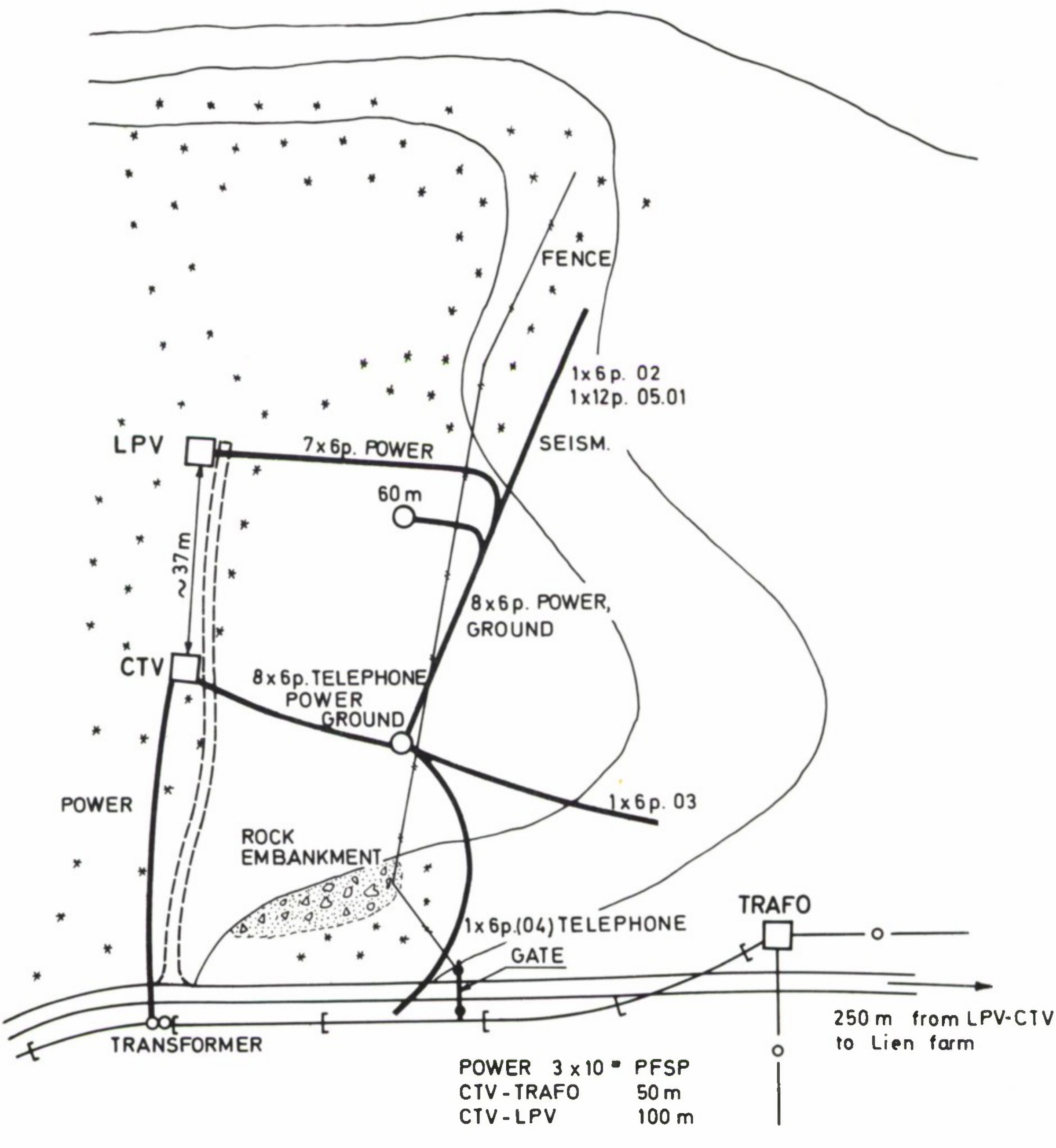


Figure 2.19 Central area, subarray 01B Åsmarka

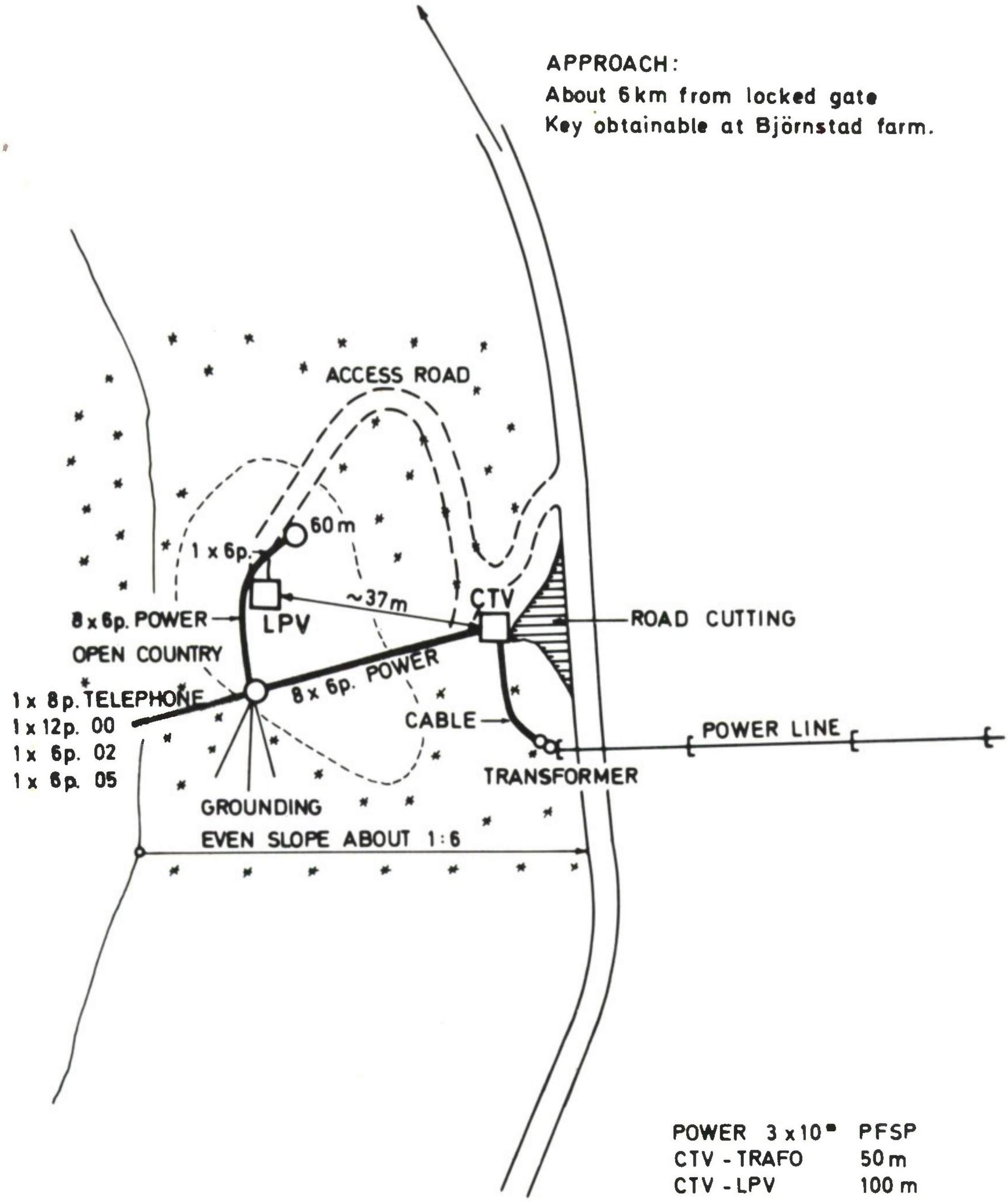


Figure 2.20 Central area, subarray 02B Rena

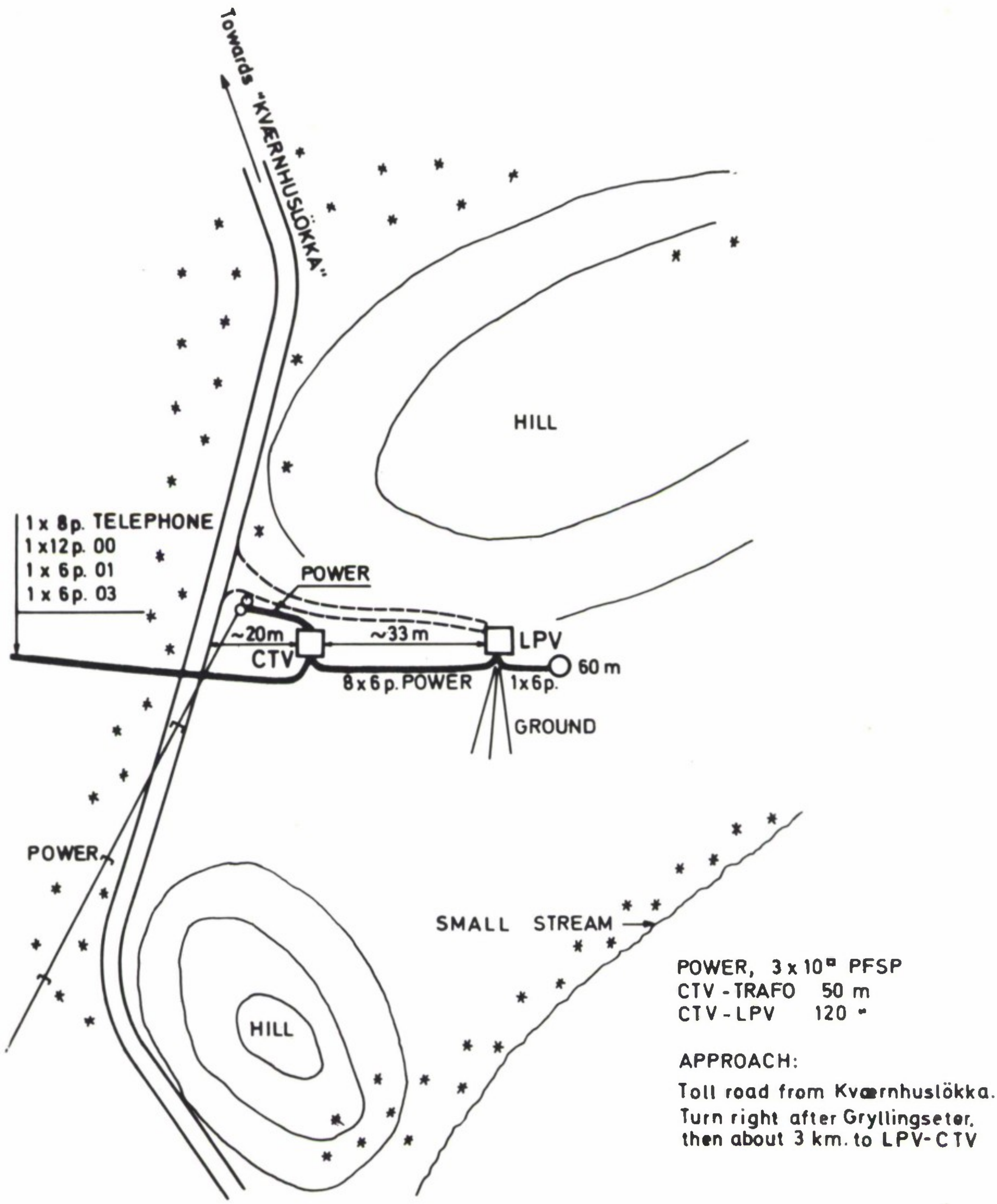


Figure 2. 21 Central area, subarray 03B Løten

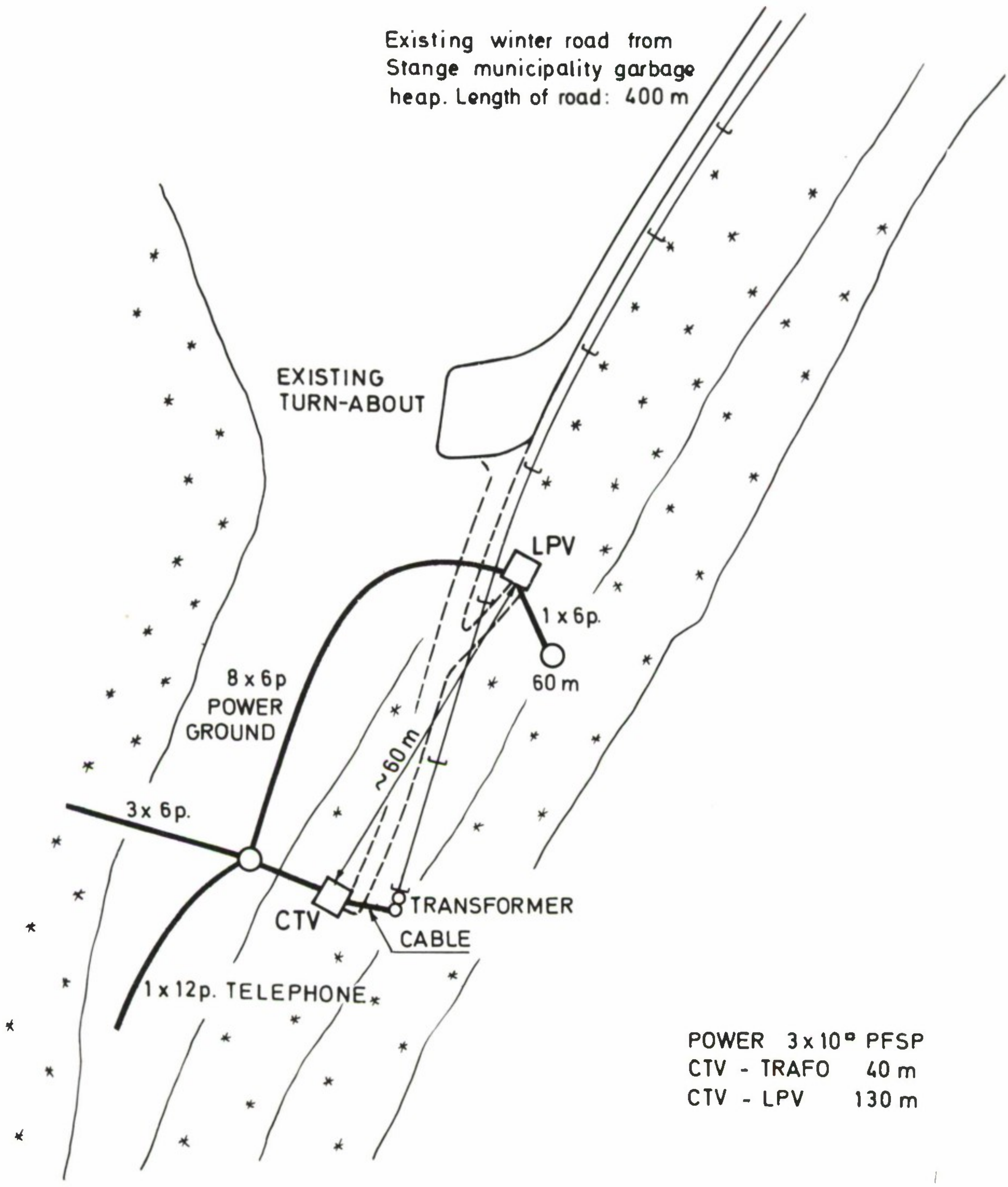


Figure 2.22 Central area, subarray 04B Stange

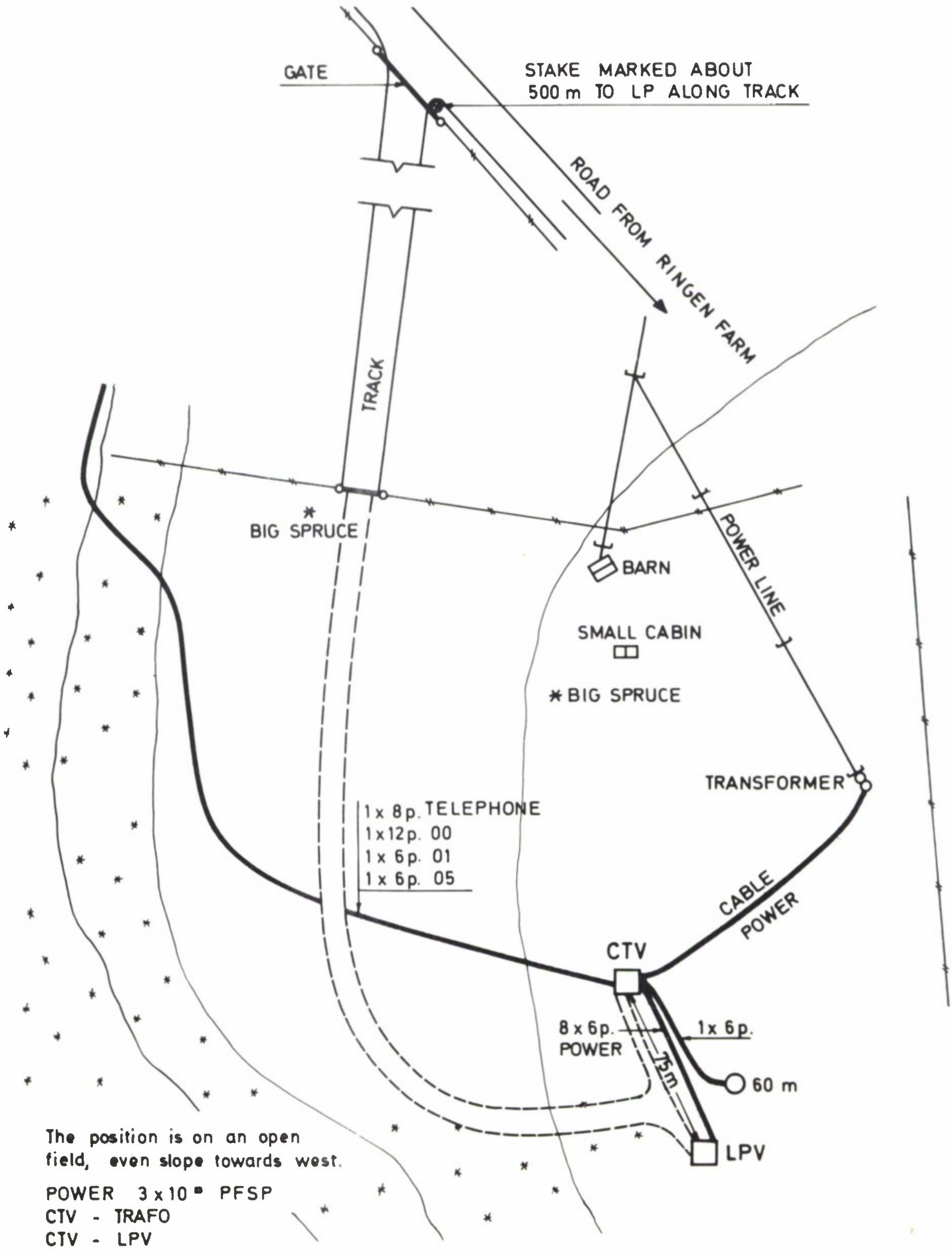


Figure 2.23 Central area, subarray 05B Toten

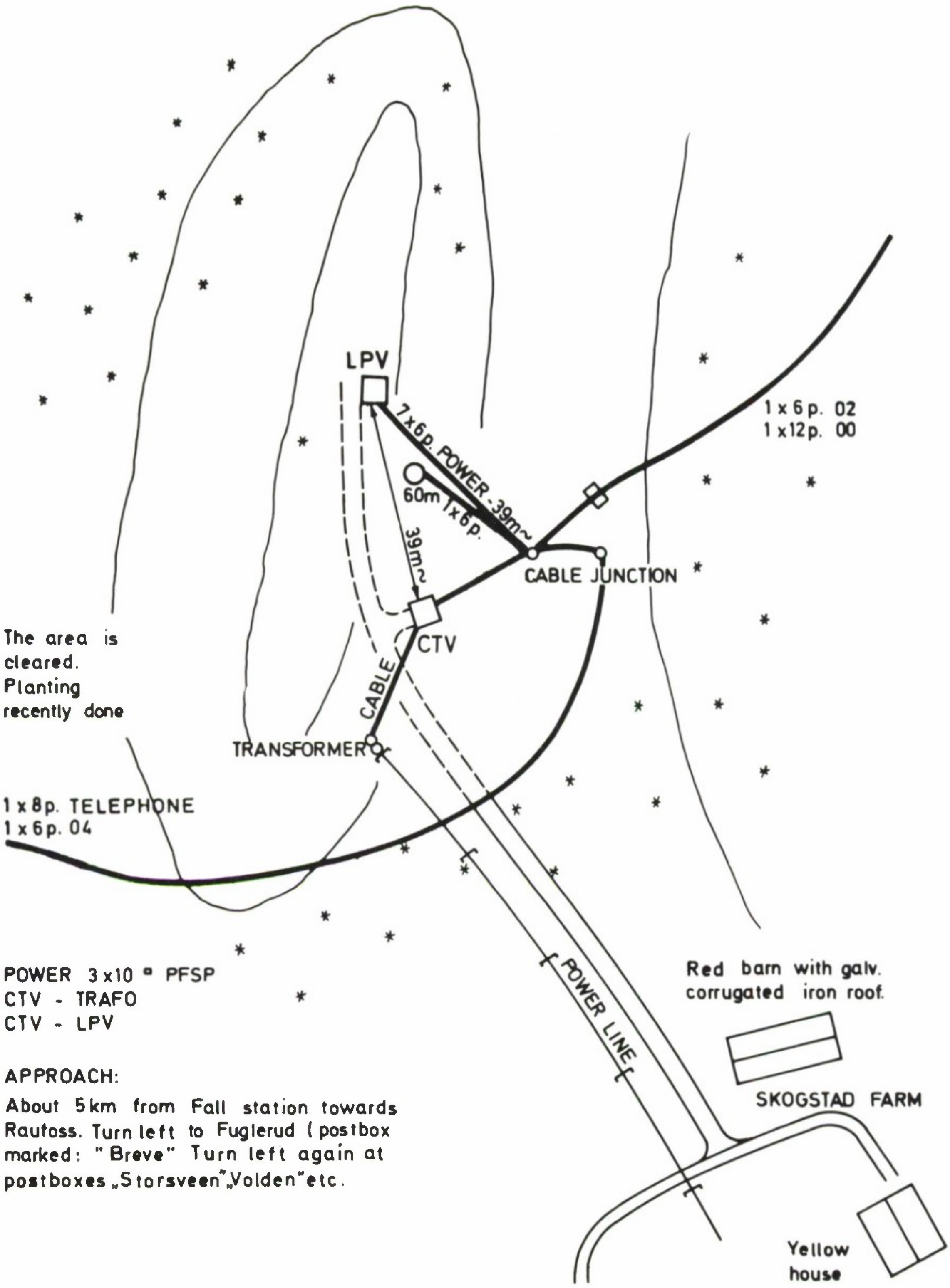


Figure 2.24 Central area, subarray 06B Søndre Land

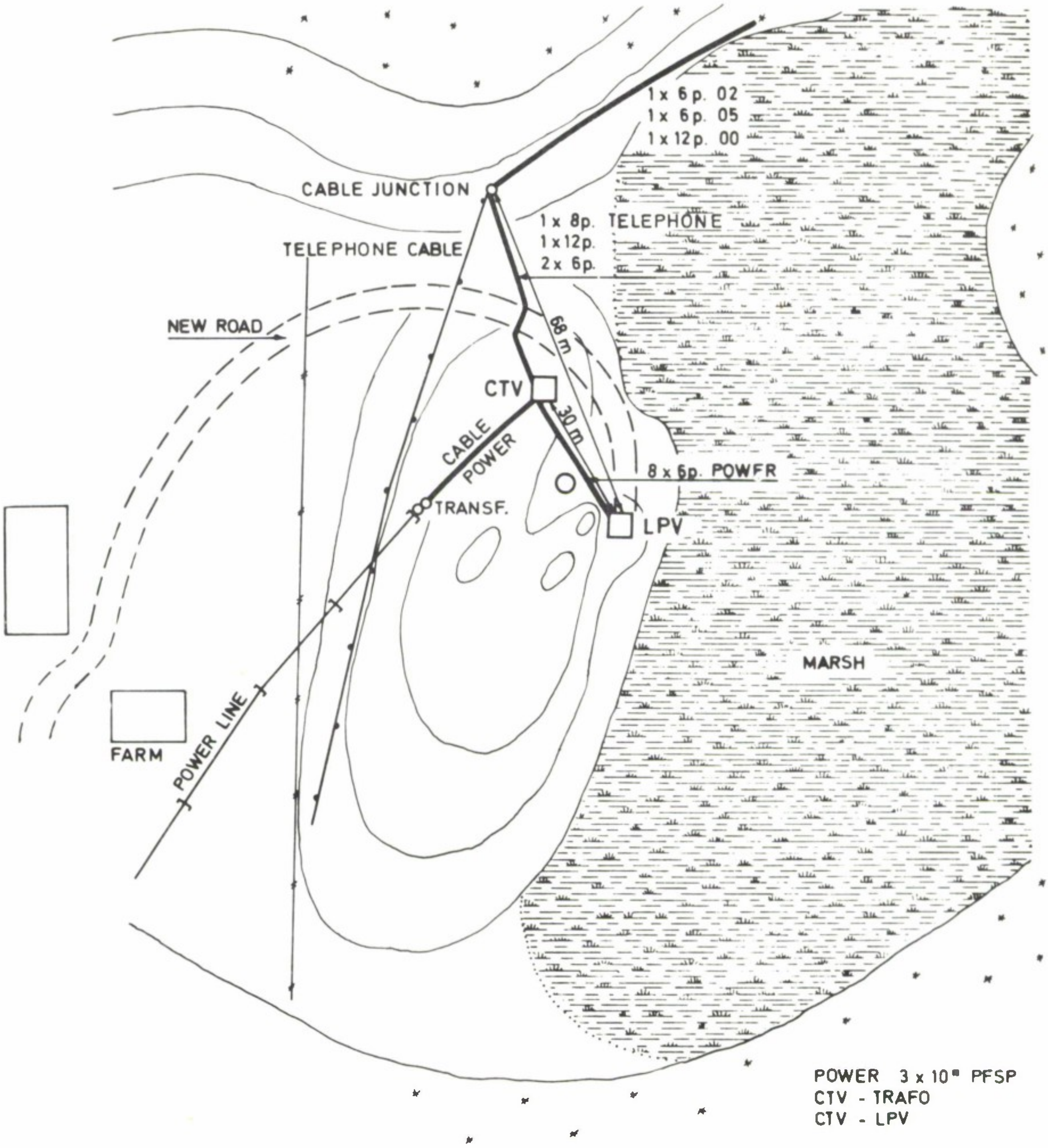
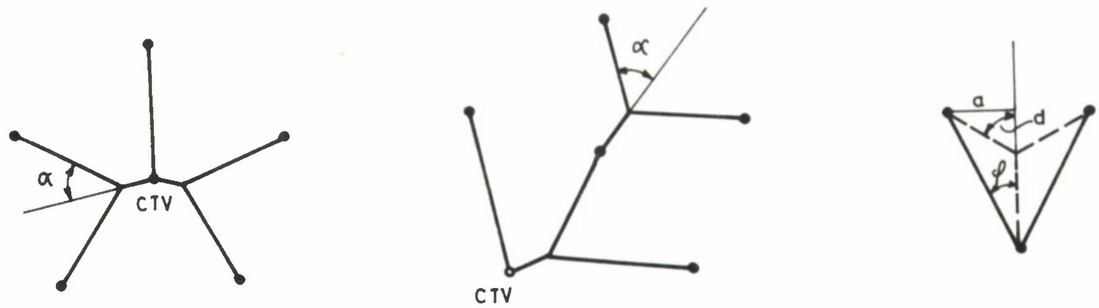


Figure 2. 25 Central area, subarray 07B Biri

With a price ratio of 2.5 to 1 between trench and cable this means 50°, and even wide variations in the ratio k/g will effect insignificant deviations from the minimum condition when an angle = 45° is chosen.



CTV in center, type 1   CTV in outer ring, type 2   Basic problem

Figure 2.26 <u>Optimizing first approximation seismic cable trench routes</u>

Some common trenches will have more than two cables; this has been taken into consideration when selecting the starting direction of the common trench.

Cable routes were traced on 1 :50 000 maps, based on these theoretical considerations and the routes were then discussed between local forest authorities and the consultants. When selecting practical cable routes, several conditions had to be taken into account. If the communication cable connecting the CTV to the Norwegian Telegraph Administration (NTA) network had to be laid in a common trench, the route was in some cases more or less fixed. In other cases landowner problems, high tension power lines or the road system largely decided the trench routes. Rock trenches were avoided where possible, both for economic reasons and because of the extra time needed for the trenching.

Finally, due consideration had to be taken to the practical trenching operations carried out by tractor back-hoes. The contractors were therefore permitted to adjust the cable routes somewhat to avoid difficult stretches. This correction was carried out before trenching started and the cable routes were finally inspected and accepted by the site supervisors.

At an earlier stage the local forest intendants or other qualified local people had returned preliminary cable routes and lists of landowners which were handed over to the land acquisition staff. The site supervisors then started to contact the landowners about their special wishes regarding trench depths and other special considerations.

The following prices were used for the cost evaluation of the different alternative cable routes:

Trenching,	cultivated land	N kr 6 per meter
"	bog area	" " 5 " "
"	moraine	" " 12 " "
Blasting of trenches, rock		" " 25 " "

Cable laying	N kr 2	per meter
Cable price, 12 pair	" " 7.50	" "
" " 6 pair	" " 4.50	" "

In addition, crossings of rivers, creeks, roads, etc had to be taken into consideration when looking for the most favourable routes.

The positioning of cable routes had great influence on the number of landowners involved. It was necessary to use local people for this part of the job in order to keep the number of landowners to a minimum and thus help to keep the time schedule. The normal procedure was to contact local forest intendants in each area, who were often able to point out the best routes by means of maps and air photographs only. With their local knowledge of the terrain they could do the necessary adjustments as well as present lists of landowners concerned.

At first only rough staking was done in the terrain by the forest intendants. Later a more accurate staking was supposed to be done by the contractors. This procedure was altered so that the detailed staking was also done by the local forest intendants; only minor changes were made by the contractors during actual trenching operations.

The cable routes were marked by coloured ribbons which could be seen from point to point, and later by stakes giving the trench length.

2.4 Documentation of cable routes

When the complete array is finished (summer/fall 1969) all cable routes will be photographed from the air on a scale of 1 : 15 000. The air photographs will be delivered as transparent reproducible copies on a scale of 1 : 5 000. The cable routes will be plotted on these transparencies. A separate set of transparencies will be prepared with reference to the different landowners along the routes.

The cable routes will also be marked in the terrain with wooden poles, and the position of these will be plotted on the air photographs. At the same time records from the cable routes will be presented.

3 LAND ACQUISITION

3.1 Requirements

Immediately after the Storting (the Norwegian Parliament) consented on 30 May 1968 to Phase 2 of the NORSAR project (Storting prop 128 for 1967/68), the Defence Construction Services (DCS) of the Norwegian DOD commenced under assignment from the NDRE to obtain the necessary permissions from the landowners who would be affected by the installations: cable trenches, SP and LPV/CTV vaults and access roads. Land leases for telephone lines and electric power lines were to be obtained by the local NTA district office and the power companies involved.

3.2 Initial approach

After the cable routes and the sensor locations had been established, lists were prepared of landowners involved (see section 2.3.5). Regarding the subarrays on the east side of Lake Mjøsa, 01A and 01B through 04B, time was very short (about 2 or 3 weeks) until the construction work was due to start. It was therefore necessary to apply to the landowners in two stages, first in order to obtain permission to undertake the construction work, and secondly to conclude agreements concerning limitation of the lease rights and principles for compensation for these and for damage and inconvenience.

During the next one and a half months the necessary permissions were obtained from the landowners in respect of the above-mentioned subarrays, altogether more than 100 landowners. The work permissions were acquired more easily than might have been expected, a result of active efforts on the part of the personnel from the DCS in close cooperation with the local authorities, chiefly the municipal forest superintendents and farming supervisors, as well as with building inspectors from the consultants and the geologists who established the cable routes and the sensor locations. It was also an advantage to utilise the local subcontractors as they were well suited to approach the landowners in a fitting way.

3.3 Development of a standard agreement

The system of a two-stage agreement was not a good solution for any of the parties. It was especially unfavourable to the State, because it had an extremely uncertain expropriation authority under which to acquire the necessary lease rights and restrict the landowners' rights in the vicinity of the sensor locations. On the other hand, the landowners' organisations insisted on the establishment of a general agreement defining these restrictions and the principles on which the compensation would be based. A committee was appointed composed of representatives from the State and from the landowners on the west side of Lake Mjøsa. Mr Thorvald Prebensen, Attorney-at-law, who is engaged as special adviser for the DCS, acted on behalf of the State.

In August 1968 a standard agreement was finalized (Appendix 1) in which the restrictions in the landowners' rights were clearly defined and the principles for compensation were stipulated. The provisions of the agreement with the landowners were subsequently harmonized with the provisions of the contracts with the subcontractors with a view to minimizing the State's liability for any damage caused by the subcontractors to the various properties.

The agreements with the landowners provided that the municipal forest superintendents were to submit compensation proposals which would guide the State's compensation offers. It was therefore necessary to instruct the various forest superintendents in the principles of valuation. As regards the cable routes, it was desirable to coordinate the compensation payments to the landowners with the vested rates of NTA, and equalise these payments in all the subarrays. It was moreover necessary to specify the compensation proposal, so as to separate such parts of the com-

pensation as were to be paid by Norway under the government-to-government agreement with the United States, defined as "necessary land leases and access rights to individual seismometer sites", and such damage and inconvenience as were to be paid by the United States: "all other costs involving the installation of cables and equipment, as well as any claims for damage arising from the installation, operating and maintenance of the facility". It also proved desirable to formulate the compensation offer in such manner as to give the landowners a favourable tax situation. Accordingly, it was natural to set aside an assumption expressed in the said Storting prop concerning annual rent to the landowners, and instead stipulate a non-recurrent compensation as only the latter solution would be free of tax. This latter solution also offers considerable advantages to the State, which thus avoids the administration of annual payments to the landowners. Based on the rates of the NTA, it was clear that only fairly modest amounts would be involved for each landowner. For this reason also an annual rent was an unsuitable payment method.

3.4 Completion of the 1968 land acquisition

Agreements with the landowners for subarrays 05B, 06B and 07B could be concluded after the above standard agreement had been established, and this was done by mid October 1968. The agreements were concluded in time to avoid causing the contractors any delay.

The winter came so early that the contractors in most of the areas did not have time to perform the necessary clearing and termination work on the landowners' property. The preparation of compensation proposals therefore had to be postponed until 1969 except for subarrays 01B and 02B where the termination work was completed in 1968. The compensation proposals for these subarrays, kr 27 275 ($ 3825.-) and kr 26 500 ($ 3715.-) respectively, not including telephone and power line damage, are presumably somewhat below the average.

3.5 General remarks

Subarrays 01A and 01B through 07B affect altogether 245 landowners. The registration of these agreements in the registration folios of the various landowners commenced before the end of 1968, and has involved some additional work because the titles to some of the properties were insufficient and some of the property numbers were incorrect. Problems have also arisen because neighbour landowners disagreed on their property boundaries.

When the question of consenting to the project was discussed in the Storting, several members emphasised the desirability of avoiding expropriation as a method of acquiring the necessary land leases. This attitude has guided the formulation of the applications made to the landowners. On some occasions it has also been possible to place the cable routes outside the properties of landowners who opposed installations on their ground. By not exposing the landowners to any strong threat of expropriation, it has been easier to reach agreement with them and the substantial costs of further legal proceedings have been avoided.

Agreements have been established with all landowners affected by the facilities under the 1968 program, and in no cases had expropriation proceedings to be requested.

4 LONG PERIOD AND CENTRAL TERMINAL VAULTS

4.1 Introduction

Within each of the 8 subarrays in the 1968 program, a long period vault (LPV) and a central terminal vault (CTV) were to be constructed. For several reasons it was decided that both structures be placed underground, as was the case in Phase 1.

For the LPV, the concrete had to be placed on exposed bed-rock to obtain maximum coupling to the ground. Furthermore, transmission of noise from the surface (wind, running water, animal and cultural noise) down to the seismometers had to be minimised. Thus all the LP vaults were completely buried underground with depth in bed-rock varying from site to site, depending on depth of overburden.

The CTVs were also buried underground, partly because building above ground would be in conflict with expressed wishes from the authorities, and partly for technical reasons. Compared to a building above ground, an underground structure would give the electronic equipment a much stabler environment in general, and more constant temperature in particular. Also, the better overall protection offered by the vault would probably contribute to the operational reliability of the system.

4.2 Experience with Phase 1 vaults, design modifications

In Phase 1 (see Final Technical Report - NORSAR Phase 1, sections 2.7 and 2.8) similar types of underground vaults were used, and the experience gained in 1967/68 resulted in some minor modifications to the Phase 2 designs (Figures 4.1 through 4.4).

a) All steel parts were galvanised (CTV and LPV).

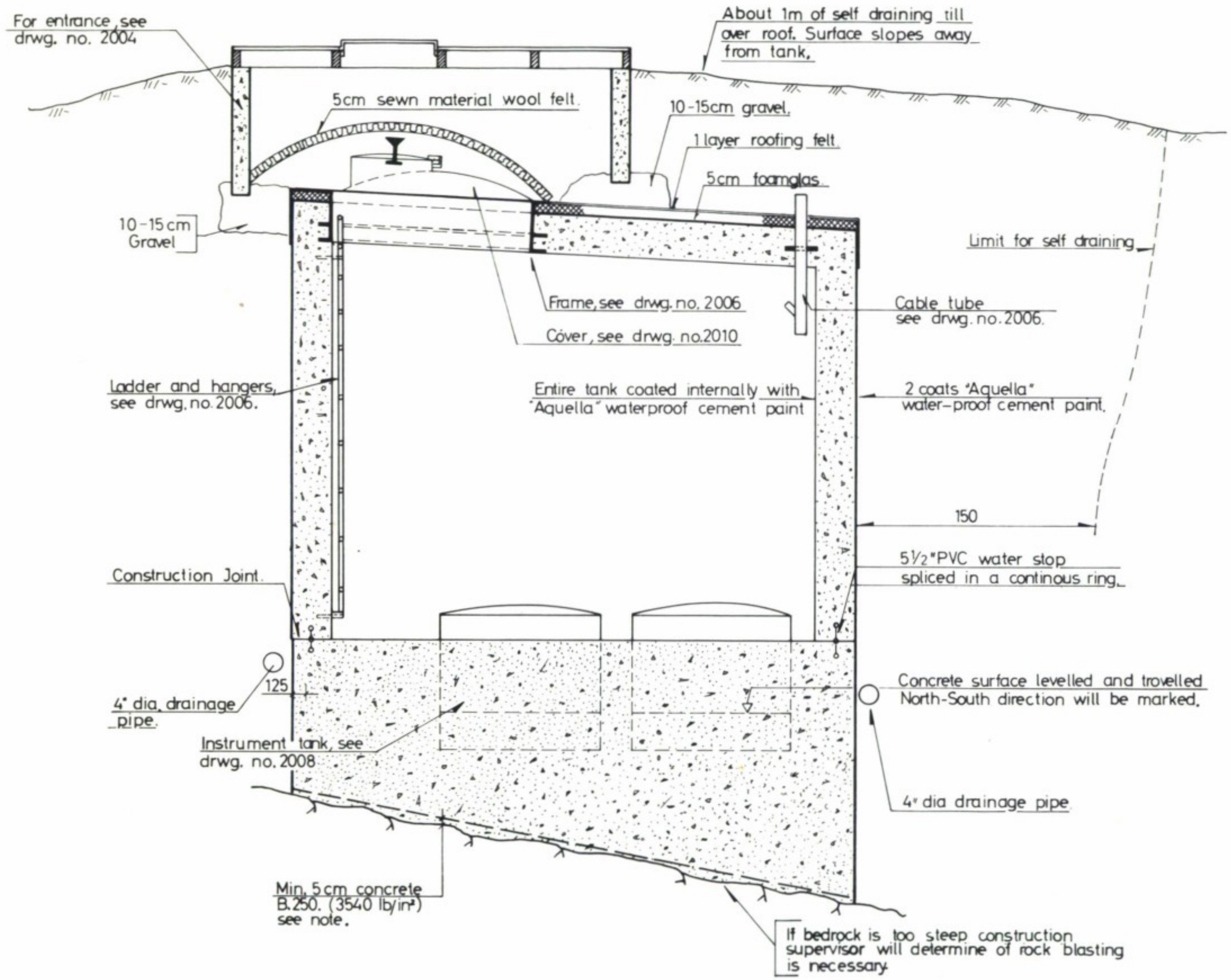
b) The concrete roof was given slope (Figure 4.5) of approximately 5% (CTV and LPV).

c) An insulation layer of 5 cm of foam glass was placed on top of the concrete roof (CTV and LPV).

d) The steel ladder was extended to facilitate access (LPV only).

e) The entrance part of the CTV was completely redesigned: An entrance shaft of concrete was cast on top of the vault roof. A hinged wooden lid lined with a plastic-coated steel plate covers the shaft. A second hinged lid is placed at the entrance of the main vault. This lid is made of galvanised steel plate filled with foam-plastic insulation (Figure 4.6).

The last modification was based on experience gained during winter 1967/68 with the Phase 1 CTV, which had only one steel lid to cover the entrance, a detail that



NOTE :

Prior to placing structural concrete, Foundation surface shall be levelled with min 5cm. B.250.(3540 lb/m²) concrete cleaned of debris and roughened for following placing of concrete.

Concrete B 300 according to class B of NS 427 (4260 lb/m²)
Reinforcement KS 40 (4000 kg/cm²).

Dimensions in centimeters.

SECTION A-A.

Figure 4.1 Long period vault; section

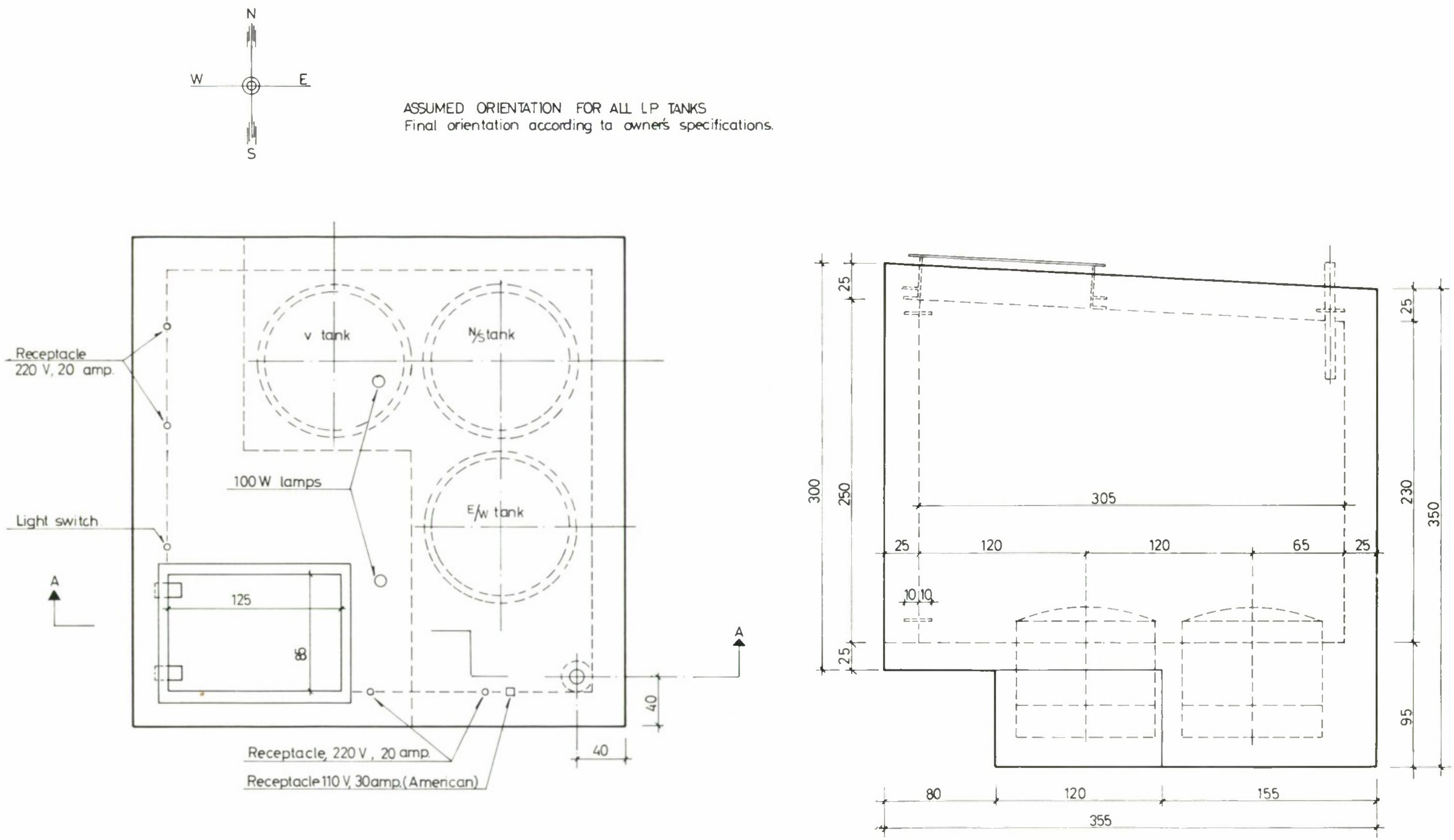
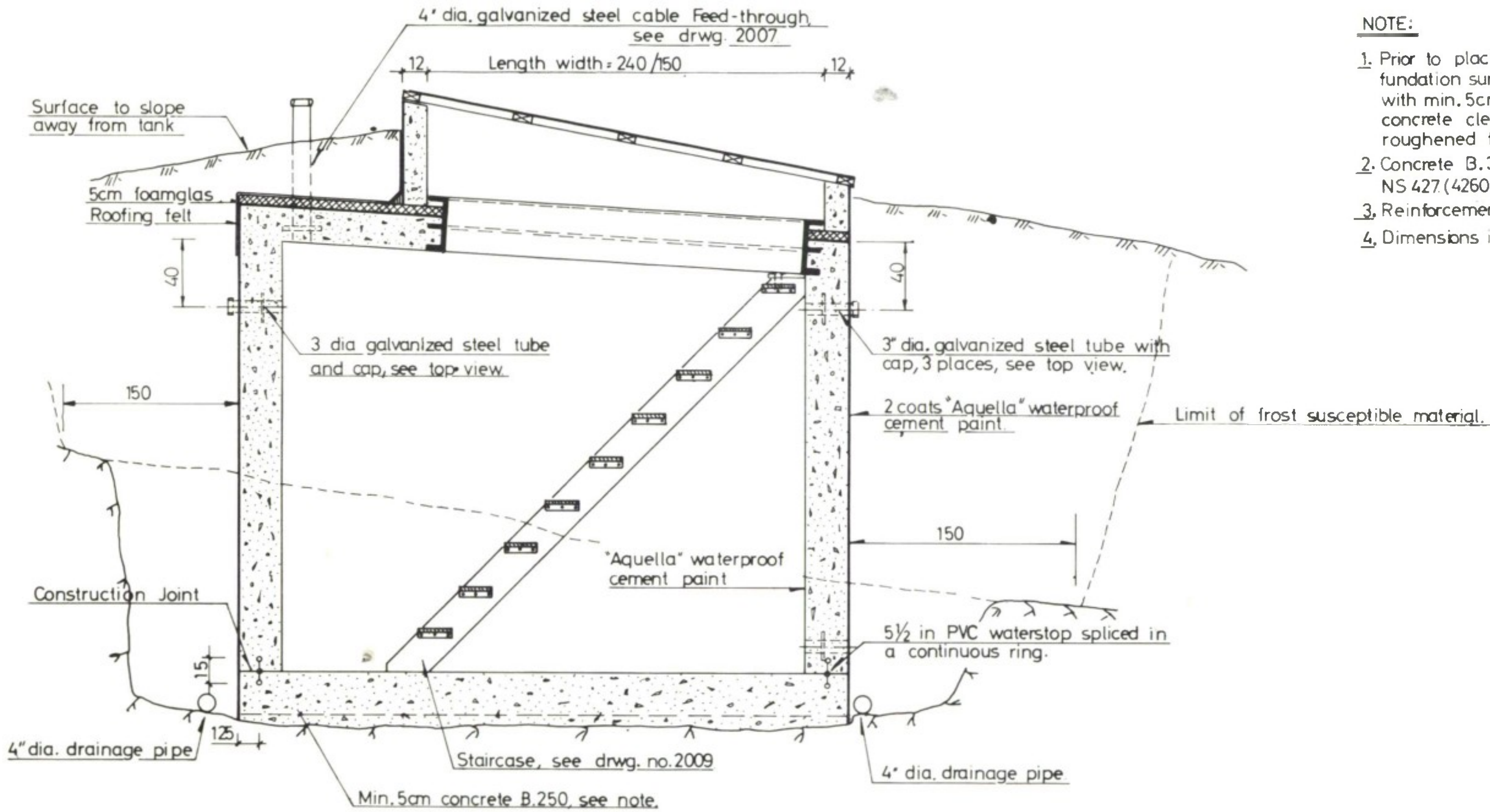


Figure 4.2 Long period vault; top view and elevation



NOTE:

1. Prior to placing structural concrete, fundation surface shall be levelled with min. 5cm B.250 (3540 lb/in²) concrete cleaned of debris and roughened for following pour.
2. Concrete B.300 acc. to class B of NS 427 (4260 lb/cm²)
3. Reinforcement Ks.40 (400 kg/cm²)
4. Dimensions in centimeters.

Figure 4. 3 Central terminal vault; section

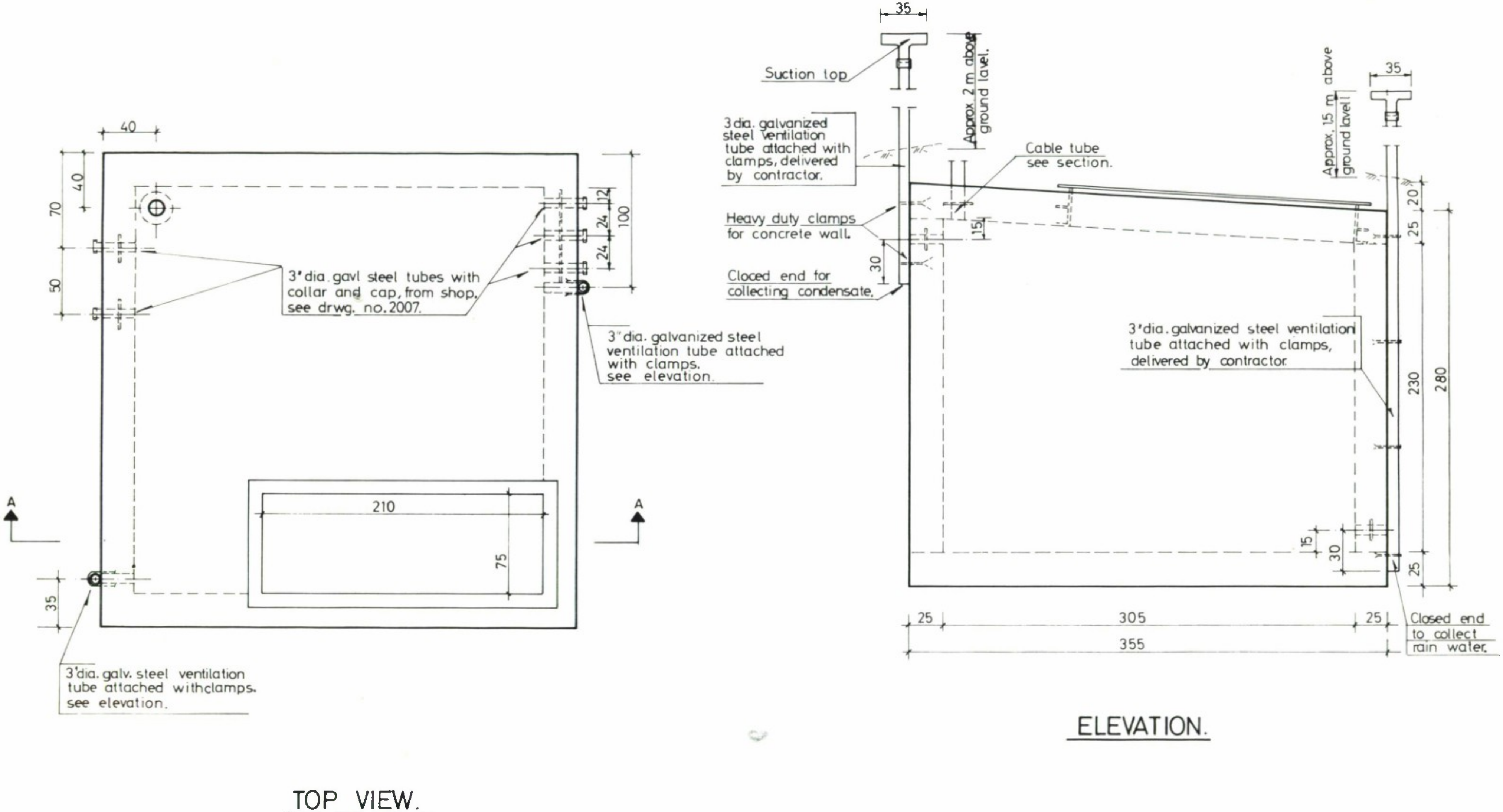


Figure 4.4 Central terminal vault; top view and elevation

introduced a couple of problems. First, the lid did not provide sufficient protection from snow, ice and water. Secondly, water condensed on the underside of the steel cover when the ambient temperature fell below the temperature inside the vault. Introduction of an entrance shaft with two covers should reduce or eliminate these problems.

The final designs are shown in Figures 4.1 through 4.4. Further details regarding design and experience obtained during construction are discussed later.

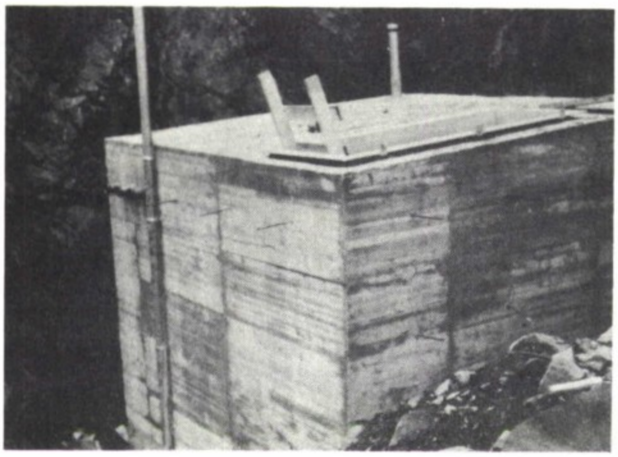


Figure 4.5 CTV before backfilling and erection of superstructure

Figure 4.6 Top of CTV with lids open, before final landscaping

4.3 Subcontractors

4.3.1 Hardware

All hardware (instrument tanks, cable ducts, ventilation ducts, ladders, manhole covers with frames, and steel doors with frames) was manufactured in a steel workshop.

Tender documents were sent to four different firms on 25 May 1968, based on an order dated 5 June. However, when the tenders were received, the agreement between the governments had still not been signed, and ordering had to be postponed.

After revised delivery dates had been received from the firms, the order was placed with Ing L Brinchmann Mek Verksted, Oslo. This firm offered the second lowest price, and was the only firm able to deliver the steel parts early enough for the revised construction program. Choosing the lowest tender would have caused one month delay.

4.3.2 Civil works

Tender documents for the main building contract were sent on 7 June to ten different firms, mainly smaller contractors within the Mjøsa area. Five tenders were received. Prices varied considerably, the main reasons for the price differences being that a relatively large part of the costs represented transport and road construction, which were difficult to estimate within the rather short tender period. The lowest tender was accepted for all sites, the successful contractors being Hagen og Godager, Stange, for the subarrays 01A, 01B, 02B, 03B and 04B, and Lars Grønvold A/S, Lillehammer, for the remaining subarrays, 05B, 06B and 07B.

Table 4.1 presents some quantitative data concerning the construction.

Site	Name of contractor	Field work started	Vaults ready to receive instruments	Foundation depth in rock for LPV m
01A	Hagen og Godager, Stange	24.8	19.10	3.0
01B	- " -	23.9	9.11	0
02B	- " -	26.8	26.10	1.8
03B	- " -	24.9	16.11	0
04B	- " -	6.8	27.9	2.5
05B	Lars Grønvold A/S, Lillehammer	5.10	9.11	3.0
06B	- " -	7.9	19.10	3.0
07B	- " -	26.8	27.9	3.0

Table 4.1 Data concerning construction of CT and LP vaults, 1968 program

4.4 Problems during construction

At site 04B, a zone of "swelling clay" was exposed during blasting for the LPV. Additional blasting to avoid the swelling clay zone was not successful. It was hence decided that the LPV could not be placed at the originally planned location. However, since the expanding zone could well be used as a foundation for an ordinary building, it was decided to interchange the locations of the LPV and CTV, thus making use of the already executed excavation work. At this stage the outer formwork for the CTV had been erected, and concrete blinding for the floor had also been cast. To ensure a good connection between the LPV floor and the bedrock, the cast concrete blinding was broken and removed and the rock surface cleaned according to specifications for the LPV construction.

The new LPV location is at the foot of a relatively steep hillside. Thus, only three sides and the top surface of the vault are buried, leaving one side exposed. To minimise the effect of wind noise and temperature variations, the exposed wall was covered with 5 cm foamglass insulation, with a 1 - 1.5 m thick rock wall on the outside (Figure 4.7).

Figure 4.7 Central area at 04B (cf Figure 2.22)

At site 01B the depth to bed-rock was approximately 5.5 m. Here the rock surface was cleaned and mass concrete placed in the excavation to bring the LPV up to a reasonable level. The CTV was founded on undisturbed soil.

The depth to bed-rock at 03B was approximately 8.0 m, i e about 2 m deeper than estimated from seismic soundings and test drilling. The discrepancy was due to a 3 m thick layer of hard glacial moraine near the rock surface. The method of construction was the same as for 01B, and a 2.5 m high mass concrete pedestal separates the instrument vault from the bed-rock.

The problems mentioned above led to relatively high costs for the vaults at 01B, 03B and 04B, and a very long access road (650 m) added considerably to the cost of the 05B vaults.

The weather conditions were relatively good most of the construction period. However, from the middle of October the temperatures fell, and freezing occurred especially at the highest locations. This did not hamper the construction work to any great extent, but the final backfilling and landscaping was made difficult at some lo-

cations because of frozen materials. Some settling of the backfill was expected at these places during the spring thaw. Also, some of the access roads froze before the final grading could be performed.

All sites were inspected in Spring 1969, and NDRE decided that minor additional work concerning access roads and landscaping was needed at some places.

4.5 Recommendations for the 1969 program

In the 1968 program all vaults were completed early enough to avoid delays in the instrumentation program. However, the average construction time for each vault was longer than first anticipated by the contractors. It seems that the contractors in general were too optimistic when the progress schedule was set up, and that they were not sufficiently prepared to tackle difficulties arising from hard rock (drilling, blasting), unexpected large depths to bed-rock, and other adverse conditions. It is therefore recommended that the contractors for the 1969 program should be contractually bound to a strict, but realistic progress schedule, and that only a limited amount of work should be given to smaller firms.

The wooden cover for the entrance to the CTV (Figure 4.6) was found to be too heavy and large for easy operation. The design will be altered for the 1969 program, either by dividing the lid into two parts, or by installing counterweights as was originally proposed for the 1968 design.

The plastic-coated steel plate that covers the entrance lid for both vaults, although provided with an uneven surface, proved to be slippery, especially when wet. To prevent accidents, the vaults for the 1969 program will revert to a skid-resistant treatment of an aluminium cover. It is recommended that such a surface (skid-resistant paint) be applied to the existing covers as well.

5 SHORT PERIOD SEISMOMETER HOLES

5.1 Hole depths

Results from the Phase 1 experimental array at Falldalen (see Final Technical Report, NORSAR Phase 1) indicated that the local (SE Norway) seismic noise conditions did not warrant the extra cost of drilling deep holes in the rock. The SP holes were therefore primarily blasted (to a depth of 1.5 to 2.0 meters) in rock outcrops; only places with extended and deep overburden made drilling necessary. An exception to the rule, the 60 m hole at each LPV/CTV site is part of further seismic noise studies, see section 2.3.3.

5.2 60 m holes

The installation of these holes was contracted to Norsk Dypbrønnsboring A/S, Sandvika. Two drill rigs were used: models Stenuick HS-5 and Stenuick Perfo. These rigs are equipped with a down-the-hole drillhammer and are very efficient in drilling vertical holes accurately.

The drilling was based on a nominal bit diameter of 165 or 170 mm. In practice the bit diameter was often somewhat less (say 160 mm) due to wear. During the drilling operation the inclination of the drill hole was checked at every 10 m of depth by means of an electrolytic inclinometer especially designed for this job (Figure 5.1). The inclination should deviate less than 3^{o} from the vertical at the depth corresponding to the seismometer position.

Figure 5.1 Electrolytic inclinometer

Figure 5.2 Tube scaffolding for placing of casing tubes in boreholes

Subsequent to completion of the drilling, removal of the drill rig and cleaning of the hole for mud, a provisional tube scaffolding (Figure 5.2) was erected to enable positioning of the sealed bottom casing over the hole. The casing steel tubes (140 mm OD, 132 mm ID) were delivered in lengths of max 10 m. Complete cementing from bottom to surface was specified for the 60 m holes. The cementing procedure was identical to that used for the Phase 1 60 m holes, and is described in detail in (1).

The work proceeded satisfactorily for all 60 m holes. No steel casing was used in hole 06B03 to make this one an experimental hole for testing whether the lack of casing had any influence on the reception of the seismic signals. Hole 06B03 was chosen because it was the most favourable as regards fault-free bedrock.

5.3 Long holes

(Holes through the overburden and 3 m into bedrock)

This work was performed by Entreprenørservice A/S, Høvik.

Figure 5.3 Drill rig for long holes

Two drill rigs were used for drilling the long holes, both were type Lindø drill rig equipped with Atlas BBE51 drill hammers and separate rotation together with chain feed (Figure 5.3).

Before the final site was selected, the overburden at every site was checked by predrilling a small drillhole of diameter 2.75".

The drilling of the main hole through the overburden was carried out by means of an 8" compact drillbit together with an outer steel casing equipped with small rim drillbits at the lower end. This equipment had a limitation of 10 m drilling depth in overburden, but was very suitable for drilling through thick morainic material even when it consisted of big boulders.

When reaching bedrock, another 3 m was drilled in solid rock. First a 76 mm drillbit equipped with direction control in the center of the casing was used, then the hole was enlarged using reaming drill bits of 5" and finally 8" diameter (Figure 5.4). The inclination was checked in the same way as for the 60 m holes.

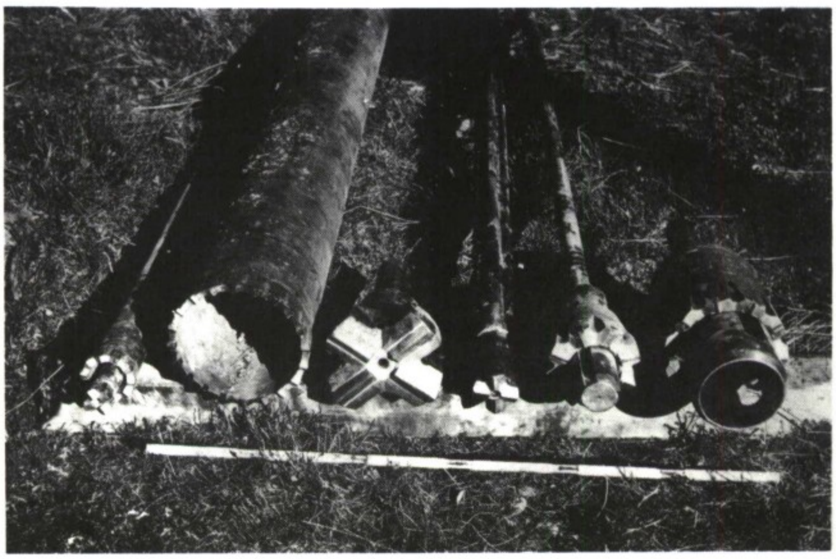


Figure 5.4 Various drill bits used for test and pre-drilling, and final drilling through overburden and rock

The 140 mm steel tubes for lining the holes were welded together (Figure 5.5), provided with a bottom end seal, and pressure tested with 7 kg/cm^2 (Figure 5.6).

Figure 5.5 Welding of casing tubes

Figure 5.6 Pressure testing of welded casing tubes

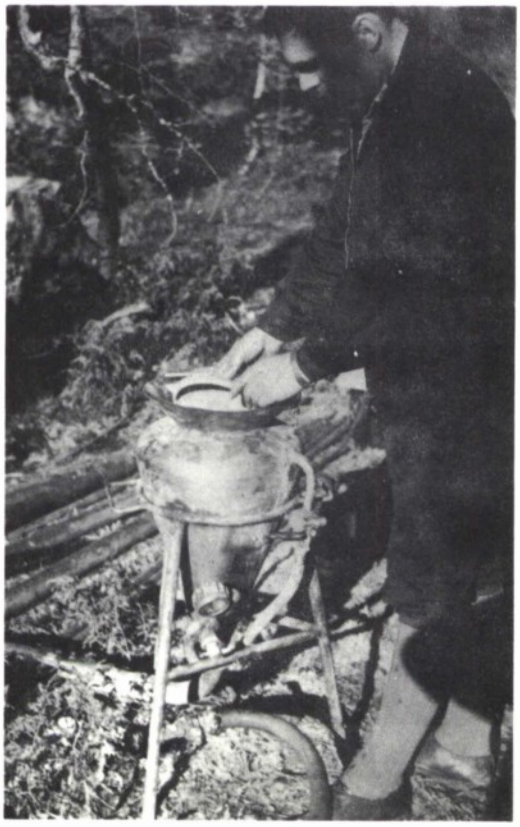


Figure 5.7 Pump for feeding concrete grout

Subsequent to the completion of the drilling and cleaning the hole for mud, specifications called for cementing to rock of the lower 3 m of the steel casing. Before removing the 8" drill casing, the mortar (consistency of flowing concrete grout) was pumped to the bottom of the hole by means of a concrete pump, type Berg Jet (Figure 5.7). The 140 mm steel casing was then pressed down into position by means of the drill rig. Later the outer 8" drill casing was removed. Figure 5.8 is a section through a complete hole, including casing and well head vault (WHV).

Other equipment used in the drilling operations was portable welding plants, compressors and water pumps.

The progress of the work was satisfactory. Some difficulties arose in conjunction with drilling details and water supply to the sites. In some cases water had to be transported in tanks to the sites.

5.4 Shallow holes

The construction of the shallow holes was carried out by two contractors: Hagen & Godager, Stange, and A/S Linjebygg, Molde.

Figure 5.9 shows the design of the shallow holes. The groundwork for the shallow

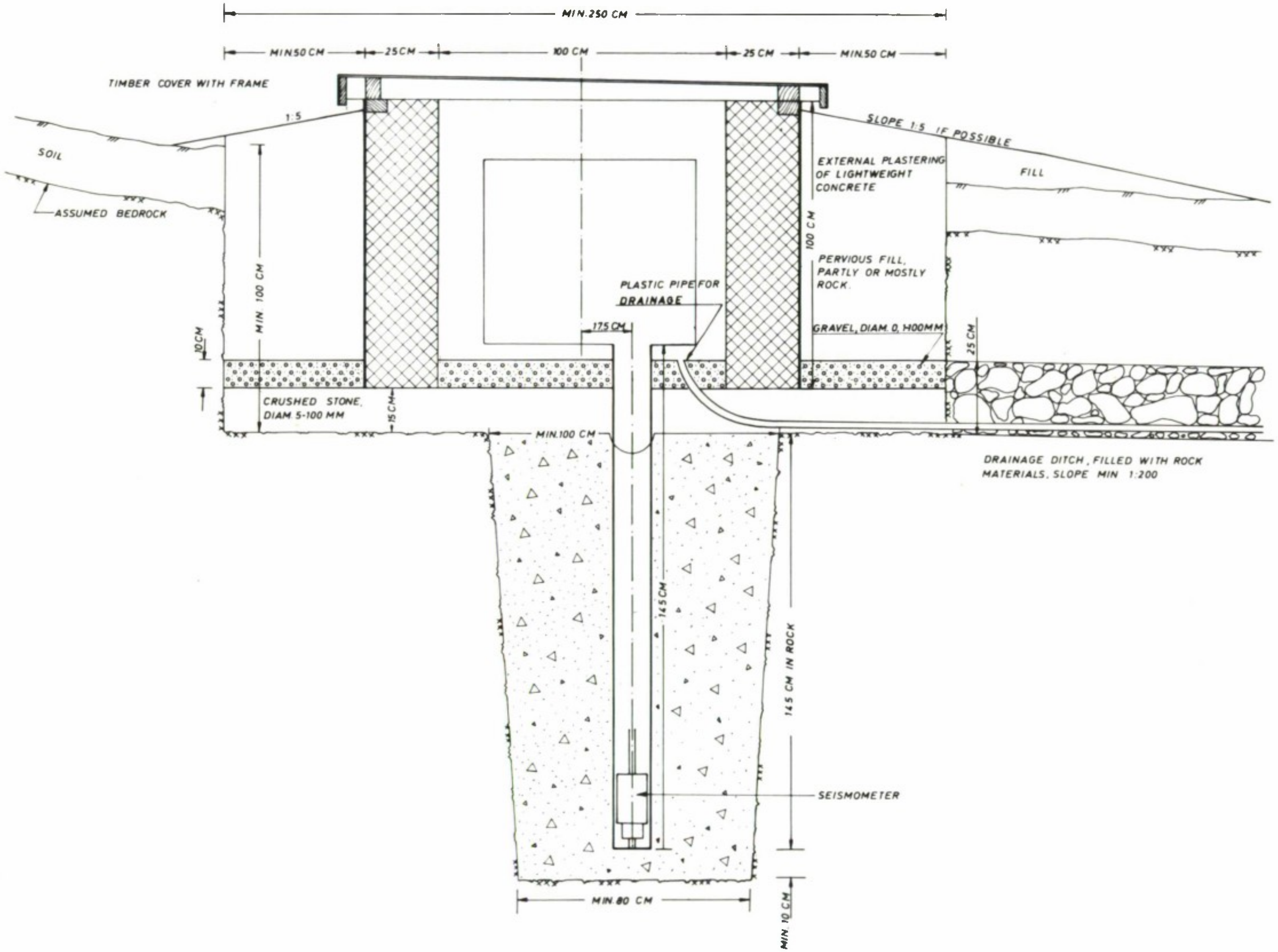


Figure 5.8 Long hole, complete with casing and WHV

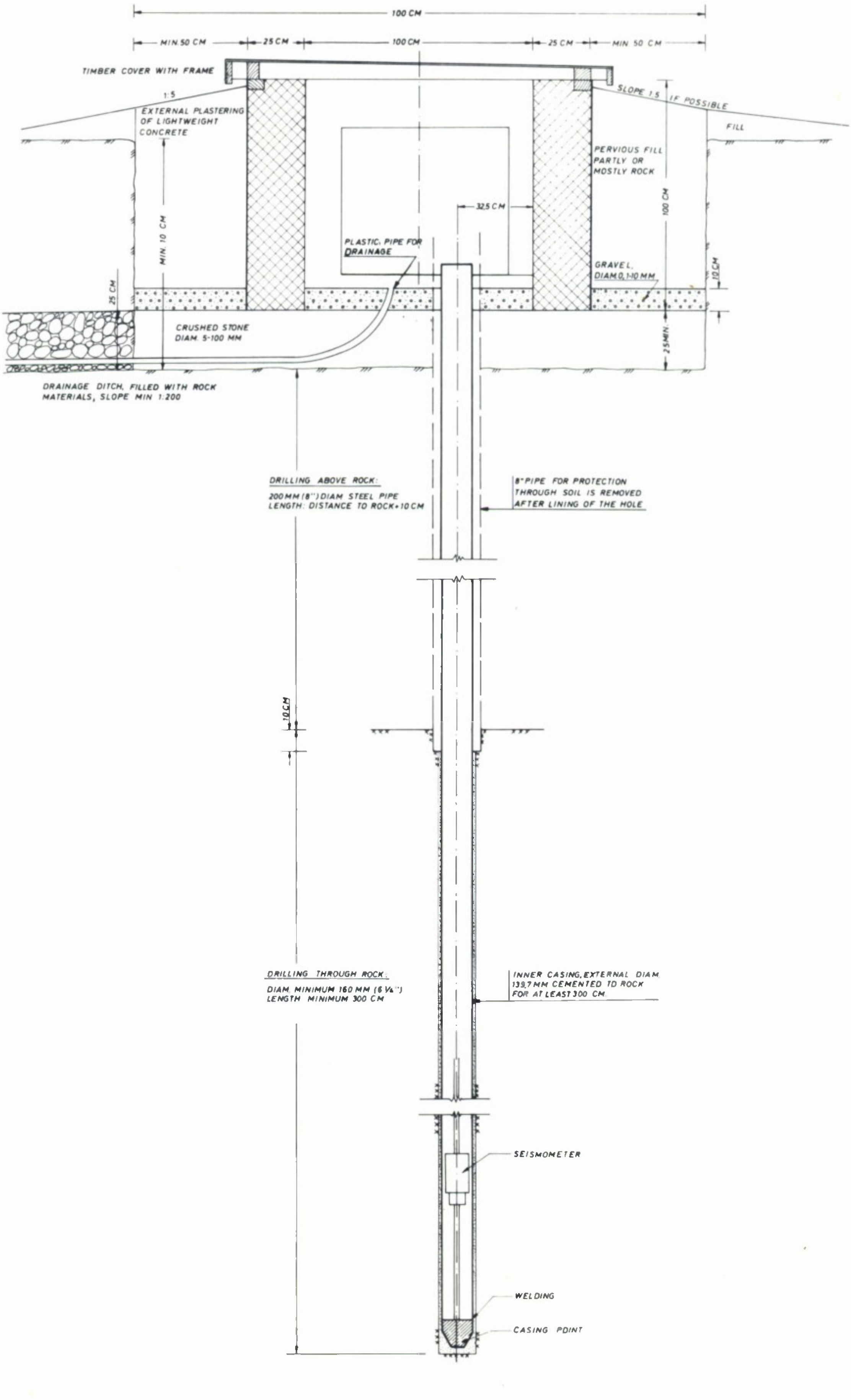


Figure 5.9 Section of shallow hole

holes consists primarily of a 1.5 m deep shaft blasted into solid rock (for the seismometer casing) and a 1.5 x 1.5 x 1.0 m deep hole (for the buried well head vault) blasted and/or excavated in the ground (Figure 5.10). A special drill hole pattern was used in order to minimise the volume of blasted rock.

Figure 5.10, Blasted and cleaned shallow hole

The drilling was performed by means of portable drilling machines, type Atlas-Cobra. In most cases this type of drilling machine was adequate for the job, but on sites where the bedrock was very tough, more powerful pneumatic drilling machines had to be used. In terrain with difficult access compressed air had to be supplied from tractor mounted compressors.

The blasting was carried out in two ways, of which the most common was to blast the upper part of the hole separately and later the shaft. The other method was to blast the hole round in one operation.

After thorough cleaning of the hole, the next step was to position and secure rigidly the short casing tube in the hole, and then fill the shaft with concrete (Figure 5.11).

To prevent future flooding of the WHV, a drainage ditch had to be provided (Figure 5.12).

Figure 5.11 Cementing of casing tube, shallow hole

Figure 5.12 WHV with drainage ditch (lower left) before backfilling and fitting of vault lid

6 SEISMIC SIGNALS TRANSMISSION WITHIN SITES

6.1 Planning, subcontracting

Based on decisions and experience from the 1967 program, signal connections between the SP- and LP-seismometers and the CTV in each subarray were to be provided by ditched cables. Other connections would be almost as costly and time-consuming to establish, certainly very much less reliable in operation, and also less acceptable to the landowners.

The routing of the trenches is discussed in Chapter 2. As for the depth of the trenches, it was originally planned to be 50 cm except for rock trenches, which were to be 20 cm deep. Landowners, forest authorities and the Norwegian Telegraph Administration (NTA) all had their special views regarding trench depths, however, the result being that several depths, ranging from 20 to 120 cm, had to be stipulated. Quite large stretches had to be 120 cm deep and considerable increases in trench costs above the bid sums was the result. On the other hand, the cable connections undoubtedly became better protected against damage from activities carried out on the surface.

The necessary specifications, bills of quantity and other tender documents for trenching and cable-laying were produced and sent to six different contractors on 30 May. Tenders were received and opened on 19 June, and contractors chosen in July. Table 6.1 contains information regarding contractors, time schedules and other relevant figures.

Necessary quantities of cables were also ordered early in July, after collecting quotations from several suppliers in USA and Norway. The cables were ordered from Standard Telefon og Kabelfabrik A/S, Oslo, as this factory offered the lowest prices and acceptable delivery times. The order was placed rather late relative to the trenching season and it was evident that trouble with the cable supply might arise.

Cable specifications are listed in Appendix 2.

6.2 Progress of work

Cable deliveries started in the middle of August and were completed by the end of October. This meant delayed progress compared with the trenching schedule, especially in the beginning, and the completion of the work and the following inspection had to be carried out partly under winter conditions. Some inspection and finishing work even had to be postponed until Spring/Summer 1969.

Trenching (Figures 6.1, 6.2 and 6.3) was started by the contractor, Kr J Braaten, in the middle of August at subarray 01B, and this array was completed within six weeks. During inspection it was found that the dressing of the terrain after completion of the backfilling was not up to standard, and final dressing by hand was ordered. This delayed completion until 25 October, when only marking was left. The same contractor started his next array, 05B, in the middle of September and completed the work 15 November, just before full winter conditions set in.

Array	01A	01B	02B	03B	04B	05B	06B	07B
Contractor	Hagen & Godager	Kr J Braathen	A/S Linjebygg	A/S Linjebygg	Hagen & Godager	Kr J Braathen	A/S Linjebygg	A/S Linjebygg
Work started	25 Aug	15 Aug	5 Sep	20 Sep	25 Aug	15 Sep	20 Oct	25 Sep
Work completed	30 Oct	25 Oct	5 Nov	30 Oct	5 Nov	15 Nov	20 Nov	15 Nov
Length of rock trenches	6.15 km	0.34 km	0.18 km	0.03 km	1.27 km	0.90 km	0.41 km	0.17 km
Length of 120 cm trenches	0.18 km	2.45 km	0.11 km	0.28 km	0.10 km	1.83 km	14.72 km	5.87 km
Total length of cables	35.5 km	26.8 km	36.0 km	34.5 km	32.3 km	30.2 km	29.2 km	28.9 km
Total length of trenches	20.0 km	19.5 km	20.4 km	19.4 km	23.7 km	21.6 km	22.3 km	21.4 km

Table 6.1 Data concerning trenching and cable-laying

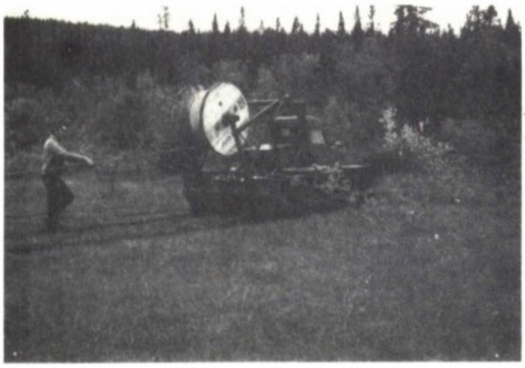


Figure 6.1 Laying of cable on the ground along the trench route

Figure 6.2 Digging of trench by means of tractor back-hoe

Figure 6.3 Placing of cable in trench

A/S Linjebygg, the biggest firm of contractors, originally planned to start work on arrays 02B and 07B simultaneously, and then continue with 03B and 06B. Land acquisition (Chapter 3) started as soon as the trench routes had been determined, but was not completed early enough to allow this schedule, and work could start on 02B only. As it turned out, the cable deliveries would not have enabled the contractor to work on more than one array. Later on, all land acquisition was completed well before any work started.

The third contractor, Hagen & Godager, started working on arrays 01A and 04B on 25 August.

It became evident quite soon that cable deliveries would limit the trenching rate (Figure 6.2). By chance this coincided with the fact that subarray 01A turned out to require far more than the usual amount of rock trenching, a very time consuming task. Both arrays were completed around 1 November, well before the winter. No special difficulties arose, although the large stretches of rock trenches caused unforeseen delays. The provisional quantities given in the specifications could not give the contractor accurate information about all aspects of the tasks. Many problems were first realised when encountered in the field.

A/S Linjebygg started work at 02B on 5 September, but as the two other contractors had received most of the cables produced, he was seriously hampered by this in the beginning.

When cables finally were available for 02B, the trenches were excavated in two weeks. However, it became obvious that backfilling, mostly carried out by hand, was progressing too slowly. The manpower available accompanied the machines, and large stretches of half-filled trenches were left behind. Winter came early in October at 02B, causing 4 - 5 km final back-filling to be delayed until spring. The rest of the work was completed.

At 07B work started late in September and the cable supply was sufficient at that time. Although additional manpower was available to work together with the machines, final backfilling was hampered because of frozen soil. Two extra machines were brought in, in order to try to complete trenching both at 06B and 07B before the winter, but final backfilling remained a problem in spite of increases in work force. At the end of the working period, i e in the middle of November, working conditions were adverse, with deep snow and temperatures far below zero. For the last stretches snow had to be cleared away by bulldozer and final backfilling performed immediately.

Figure 6.4 Splicing of cable

Cable splicing (Figure 6.4), carried out by independent specialist groups, did in no case hamper progress or postpone completion of any connection.

During checkout of the cables some faults were found at 06B, caused by rough handling of cables under winter conditions. The faults were repaired at once. It was expected that more faults would arise during the 1969 spring thaw, with the setting of the backfilling materials. Such faults were indeed discovered, and repaired during early winter 1969.

7 POWER SUPPLY

The power supply system is logically divided into three different parts:

a) Provision of 230 V (and 115 V), 50 Hz to the CTV

b) Battery standby power

c) Power cabling in the CTV and LPV

Power to each of the sites was contracted or ordered direct from the local municipal power company, which built the necessary connection either by using its own staff or by subcontracting the work to a construction firm.

In the majority of cases (Appendix 3) a pole line was constructed from the nearest existing distribution transformer in the company's network or from some local supply circuits whose carrying capacity in some cases had to be strengthened. For two of the stations, 02B and 03B, it was found more economical to use a 1000 V connection because of the distances to the nearest available public supply. Reference is made to Figures 2.10 through 2.17 for the routing of the power lines.

NORSAR Array Design (see end of 2.1) specifies a screened isolation transformer between the commercial supply and the power installation. Transformers of this kind are not conventional items for the power companies in Norway. It was also found practical to include a 115 V, 50 Hz supply in the vault. Because of these special requirements it was decided to procure transformers for all the arrays from one supplier. Normally the supplier would have been selected through a bidding procedure, but as the major transformer makers were not interested in the delivery within the short time limit required, the transformers were ordered directly from Noratel A/S on 7 August 1968.

While the running stationary load is estimated at about 250 W, there would be additional consumption due to measuring instruments, heat cycling of seismometers and heating during the installation period, and occasional re-charging of batteries during operation periods. The transformers were ordered for a nominal load of 5 kVA (Figure 7.1).

Figure 7.1 5 kVA isolation transformer mounted on overhead line termination pole (See Figures 2.18 through 2.25 for siting within the central areas)

The voltage drop on the line at full rated load on the transformer was permitted to be higher (10 - 15%) than conventional, because only non-essential circuits needed the full rating and because the final arrangement would have the essential equipment buffered by a storage battery.

Power cabling in the CTV was included in the bid invitations (issued 7 June 1968) for delivery of electronic equipment and installation of this as well as certain equipment (seismometers, amplifiers, etc) provided by the US Government. When the contract for this job was awarded to A/S Siemens Norge, it was decided to include in the contract also the supply and laying of cables from the pole mounted isolation transformer to the CTV (Figure 7.2) and LPV. In one instance Siemens would also install and connect the isolation transformer to the pole line, a job otherwise undertaken by the local power company.

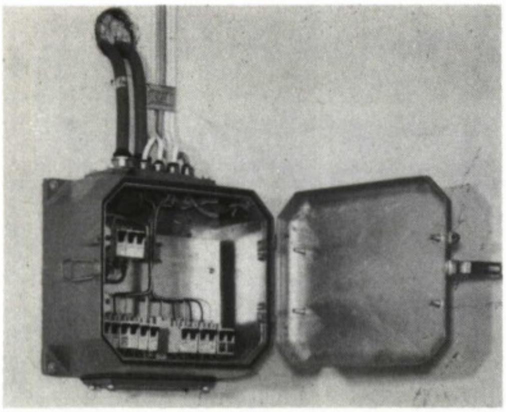


Figure 7.2 Power intake and fuse box in the CTV

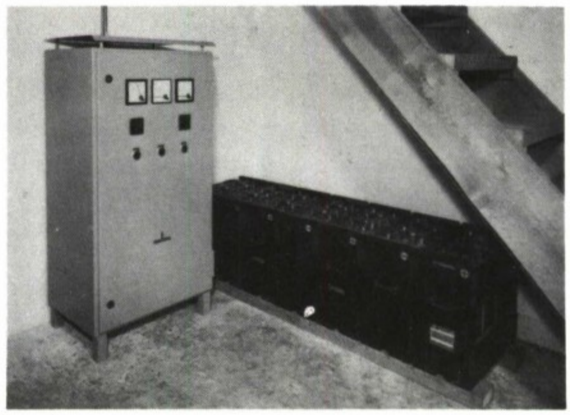


Figure 7.3 Charger and battery (battery top cover removed)

In the Siemens contract was finally included the delivery and installation of the no-break battery power supply (Figure 7.3). This could not be specified in the 7 June bid invitation because there were at that time still uncertainties as to what the specifications should be, in particular because of unknown modem loads. A more detailed account of the no-break power supply is given in Chapter 9.

8 TELECOMMUNICATIONS

8.1 Requirements

The main task of the telecommunications system would be to enable on-line transmission of seismic data from each subarray to the Data Center at the Kjeller Computer Installation (KCIN), and transmission of interrogation and command signals in the opposite direction. The width of the data channel had to be large enough to allow only insignificant loss of resolution relative to the analog seismic signals as present in the CTV.

In addition to the data channels there would also be a need for voice communications during the installation and operation periods.

8.1.1 The data circuit

In each CTV was to be installed a SLEM (Short and Long Period Electronic Module) whose task is to sample the analog seismic signals, convert the samples into suitable digital form, and transmit the data to KCIN. The SLEM Output Data Word (ODW) was to consist of 120 bits, of which 60 bits are reserved for SP data, 13 bits for LP data, the balance covers requirements for synchronization, transmission, checking, identification and control. One ODW corresponds to one sampling of the SP analog signals.

Two sampling rates would be available, 10 and 20 samples per second, producing bit streams of 1200 and 2400 bits/s, respectively.

The data transmission specification valid at the latter half of 1968 called for a dedicated duplex 2400 bits/s channel for each subarray, supplemented by a low speed duplex supervisory channel transmitted over the same line facilities. Several possibilities exist for exploiting these channels. If the concept of one exclusive line per subarray is maintained, the SLEM will be used in the so-called L (Lonesome)-mode, with a choice of sampling and bit rates as stated above. It is, however, also possible to use the SLEMs in a C (chain)-mode, intended for an arrangement by which two and two subarrays are chained together, each pair sharing a common channel. In this mode the sampling rate would be 10 samples/s and the combined data rate 2400 bits/s.

8.1.2 Voice communications, operation

The data circuit will be designed so that it may be alternatively used for telephone connection directly to the KCIN. In the CTV this is arranged by plugging a hybrid circuit between the line test jacks and a rack mounted telephone provided for the purpose. At the KCIN end, a corresponding arrangement is planned with two four-wire telephone sets available on jacks that may be plugged into any one of the 22 lines out to the CTVs. Calling facilities for a line are arranged from the CTV by transmitting a mark on the supervisory channel. The means of handling this call signal have not yet been decided. In the other direction calling facilities are not considered relevant, since the CTVs are normally unattended.

In addition to the voice channel based on the data circuit, there is need for a normal telephone connection to the public network from the CTV. This telephone circuit is arranged so that the telephone line may be extended to the LPV and the WHVs through a strip of jacks and cord lines.

8.1.3 Voice communication, installation

During the construction period, NTA's public mobile radio telephone facilities were used extensively.

Four portable radio telephone sets designed for car-mounting were bought for the NORSAR project and placed at the disposal of the ESD staff and the consultant, with the intention that these sets, after serving the construction period, would be made available for the field operation and maintenance crews. Through negotiations with the NTA, it was possible to expedite installation of two new service base stations low down on their priority list, so that better coverage of the array area was obtained. The contractors were also able to take advantage of these facilities.

8.2 Øyer (01C) subarray - KCIN data transmission tests

The Øyer CTV - Kjeller data circuit had been prepared to some extent during phase 1; a 14-pair telephone cable had been laid from the CTV to a terminal on the public telephone network.

In September 1968 the complete circuit from Øyer CTV to Kjeller was connected, equipped with ITT GH 2003 modems (Manufacturer: Standard Radio and Telephone AB, Solna, Sweden) and tested by an IBM (UK) team, using a Trend Data Transmission Test Set. The ITT modem uses straight frequency modulation of the serial bit stream making the transmission speed (in baud) equal to the bit rate.

The first attempt to transmit 2400 baud signals over the established circuit proved unsuccessful despite a high signal-to-noise ratio. A new routing involving only two instead of five carrier sections between Lillehammer and Kjeller was quickly established. From then on the bit error rate was acceptable on this stretch.

In November 1968 NTA undertook a more comprehensive test of the data circuit between Øyer CTV and KCIN and checked the group time delay as well as transmission loss across the band, the noise level, and bit error rate. The total number of bits transmitted in both directions during these tests was 45 million, the number of bits in error was 910 in the direction from Øyer to Kjeller and zero in the opposite direction.

The ITT GH 2003 modems had been subject to testing in the US with simulated lines by IBM and Mitre Corporation, and some doubt had been raised as to the suitability of these modems because they did not perform too well under marginal signal to white noise ratios. As a conclusion of the NTA tests, however, it was confirmed that they would operate satisfactorily on the type of circuits that would actually be used in the array. The difference between the conclusions may be explained by the fact that signal-to-noise ratios measured on actual circuits were found to be several tens of dB better than those applied in the simulated line tests.

Concurrent with these tests the data circuit between the SEM (early version of the SLEM, modified to take care of the LP signals) installed at Øyer and the data center at KCIN was put into operation from the middle of September. With the exception of one case of simultaneous equipment failure in the KCIN modem and an NTA line filter, this transmission of data from Øyer has worked very satisfactorily.

The equipment failure caused a long interruption in operation. This was clearly due to a lack of procedures and personnel to handle cases like this, and it is highly improbable that long delays for such reasons will be experienced when the system is in operation.

8.3 Cable connections CTV - NTA network

The number of pairs between the CTV and the NTA network was based on the early assumption that SLEMs might be connected in the chained mode, which would require four pairs in addition to the single pair required for connection to the public telephone network.

NTA do not use smaller cables than 8 pairs and this cable size has been used to connect all subarrays. Conductor diameter is 0.9 mm, and the polyethylene insulated pairs are loaded with 77 mH coils at separations of 1730 meters, giving a critical frequency of 4.5 kHz. The specifications of the cables delivered to NTA are found in Appendix 2.

In cases where the same trench has been used for both seismic and telecommunication cables, trenching and cable laying work had to proceed continuously from one end, since it is imperative that the loading coils are accurately spaced along the cable.

NTA have their own specifications for trenching and cable laying operations, which on some points of detail deviate from the ones used for the NORSAR array cables. NTA formally insisted that NTA specifications should be used where array and communication cables were placed in a common trench. The contractor for NORSAR was to take care of the laying of the cable, and the contractor's expenses for the NTA cable were paid directly by NTA to the contractor. The cable itself was procured and delivered on site by NTA, and their own inspector was present during the laying operation. All splices in the communication cable were made by NTA personnel.

Except for shortage of communication cable, which caused some delays in completing the operation, the cooperation with NTA on the common trenches worked smoothly, and the modification of trench specifications were settled between the cable inspectors in the field.

The routing of the connections CTVs - NTA network is shown in Figures 2.10 through 2.17, and the local routing within the central areas in Figures 2.18 through 2.25.

9 INSTRUMENTATION

Subsequent to a general review of the procurement and contracting for delivery and installation of the instrumentation in the seismic subarrays, and an account of the progress of implementation, the text on technical details is grouped under the following headings:

- SP system
- LP system
- No-break power system
- Physical layout of the TS cubicle

As the subarrays are to all intents and purposes identical except for minor differences in labelling and layout (due to differences in cable network geometry) the description of the technical details may be reduced to cover one subarray only.

9.1 Planning and contracting

The specifications of the bid invitation for deliveries and installation of instrumentation for the seismic arrays, which were sent out on 7 June 1968, were based, except for certain modifications on NORSAR Array Design (2). In general they were formulated as performance type specifications, leaving to the contractor the design of individual units that entered into the system. Certain items were omitted from the specifications because the interfaces were not sufficiently defined at that time.

The design specifications included, in addition to purely seismic instrumentation information, also certain items about ancillary equipment, weather station facilities, and other environmental sensors. It was decided in harmony with ESD that these circuits should be left out for the time being. The equipment should, however, be physically designed to allow incorporation at a later date of additional circuitry for interfacing other sensors with the SEM/SLEM (see 8.1.1, 8.2) and to have chassis space and power available for expansions. The bulk of the instrumentation in the CTV is contained in two large cabinets: the TS (cable termination, protection, cal circuits and controls) and the DS (data-handling (SLEM) and transmitting equipment) cubicles. Figure 9.1 shows the TS cubicle installed in a CTV. (The DS cubicle, externally almost identical to the TS cubicle, will be placed beside it. As the DS cubicle was not equipped during the period covered by this report, it will not be treated here.)

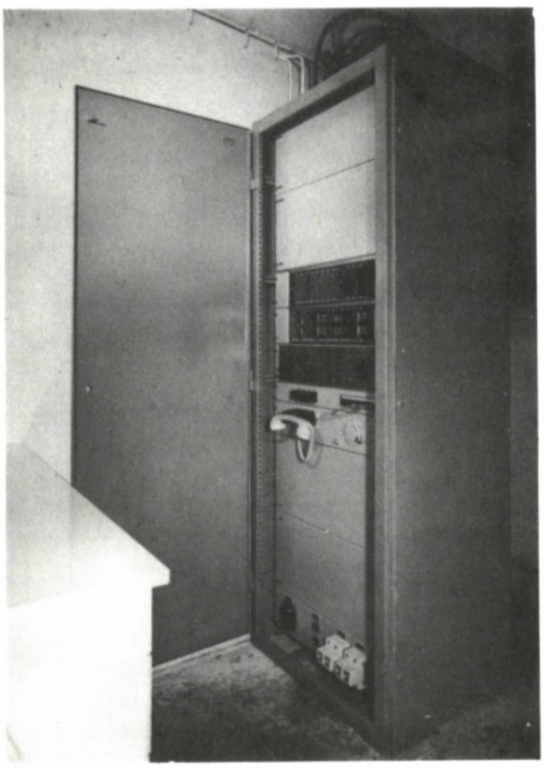


Figure 9.1 TS cabinet installed in CTV

Four bids were received in response to the invitation. Then followed a period needed for clarification of the completeness of the bids and the quality of the components to be used in the equipment. The outcome of these discussions was that the bid from Siemens Norge A/S was accepted as being satisfactory. However, in the meantime new specifications had been received for the US-furnished equipment and also changes in plans for the implementation. It was therefore decided to base the agreement on a cost plus fixed fee type of contract, as several changes relative to the specifications had to be made at that stage and still further changes were anticipated.

9.2 Implementation

With the time limit set by the start of special noise studies, timing of the production of the units was rather critical. The main obstacle to a smooth production proved to be delivery of connectors. A minor delay in the production of parts needed for the LP noise study (to be performed at stations 6B, 7B and 1A) was of little consequence, but it turned out during installation that the epoxy castings on the flanges of the terminating boxes were not airtight. However, as the pressure equalisation time constants of the LP vaults were much better than the specifications (see Appendix 4), even better than specified for the instrument tanks (Appendix 4), the recordings could be started without correcting this fault. In this way sufficient time was found to solve the problems of the epoxy castings.

The critical item for implementation of the SP arrays was the delivery of components, in particular the connectors mating the plugs on the seismometers. It was possible, however, at the expense of reducing the check-out work to a summary go-nogo test on the seismometer-amplifier chain, to bring three SP subarrays to a standard that was satisfactory for the noise study team from the Environmental Science Services Administration (ESSA), when they arrived in the last days of 1968.

9.3 Systems description

9.3.1 The SP system

The typical layout of the WHV-to-CTV linking is shown in Figure 9.2. The SP sensor in the center of the array labeled 00 is connected to the CTV by a single 12-pair cable, serving the center sensor and two sensors on the periphery. Which sensors are connected through the center will depend on the trench routing; the most convenient cable pattern is chosen (2.3.5).

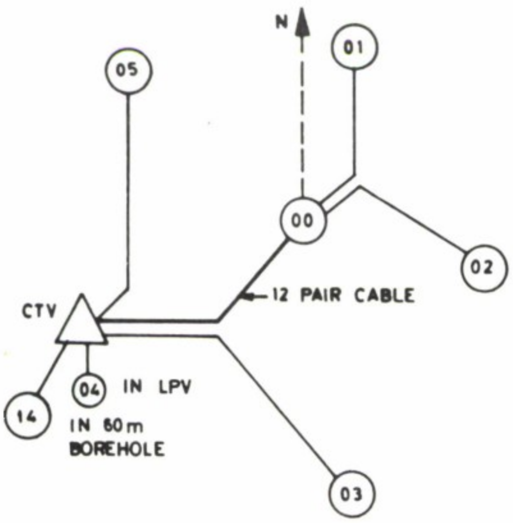


Figure 9.2 Typical layout of subarray SP cable connections

Center point - 00, other points - 0X, consecutively from 01 in clockwise order from direction N. 60 m hole near CTV - 1X.

In two cases (01B and 04B) the CTV was co-located with the center sensor, and this variant would normally require a system of 6-pair cables only. In both cases it was however found more favourable to chain two sensors on the periphery, and a 12-pair cable was laid between the center CTV and one of the peripheral sensors.

The cable pair allocation and coloring system are presented in Appendix 2.

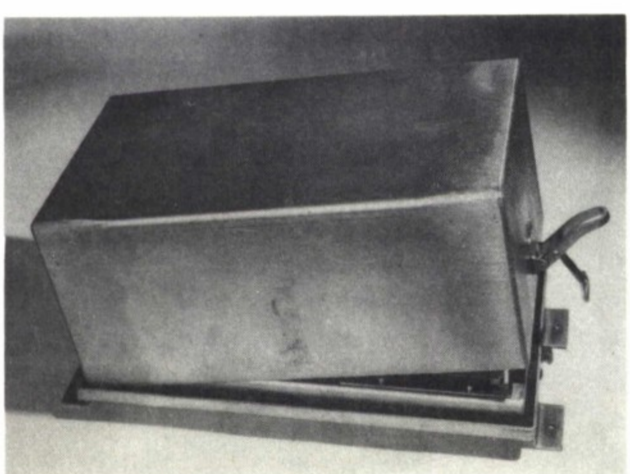


Figure 9.3 Standard box for WHV electronics

Termination equipment at the WHVs

The termination equipment in a WHV of the SP system consists of an amplifier box JA and a cable termination box JB or JC.

The design of these boxes was copied from the NORSAR Phase 1 test installation of 1967, but certain modifications were made. In the mechanical design, shown in Figure 9.3, a more reliable gasket was introduced,

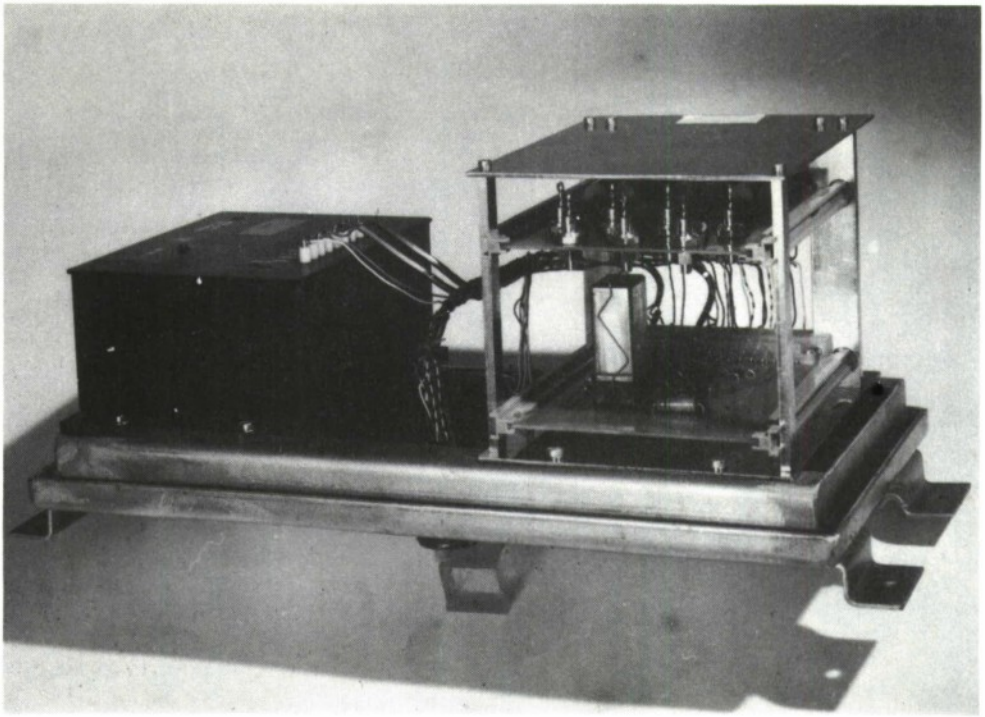


Figure 9.4 Amplifier box (JA)
(Texas Instrument RA-5 parametric amplifier to the left)

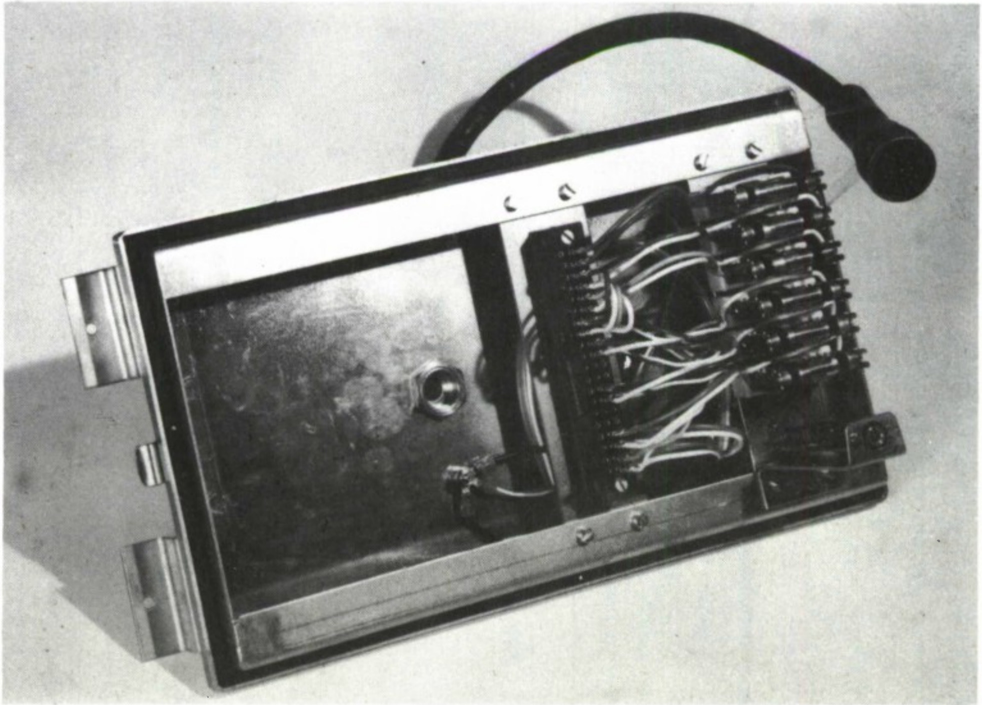


Figure 9.5 Junction box type JB
(Lightning protection gas tubes and telephone jack to the right)

and the lid locks were designed to give better pressure against the gaskets.

The JA box, shown open in Figure 9. 4, has the same layout as the one for Phase 1, but the cards and connectors were modified to follow the normal practice of the present contractor.

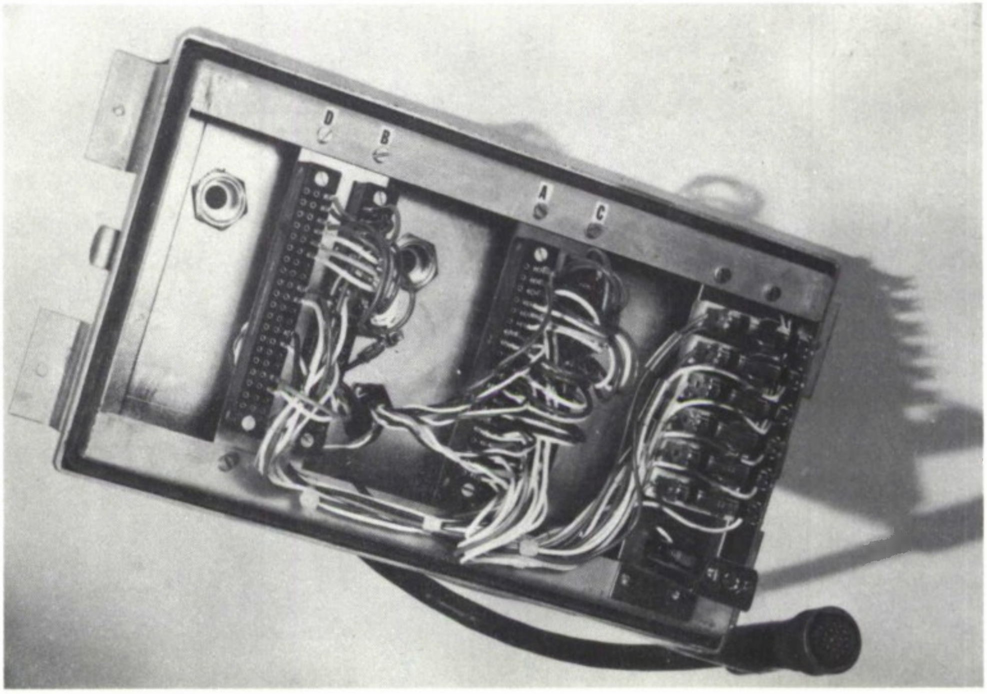


Figure 9. 6 Junction box, type JC for branching points

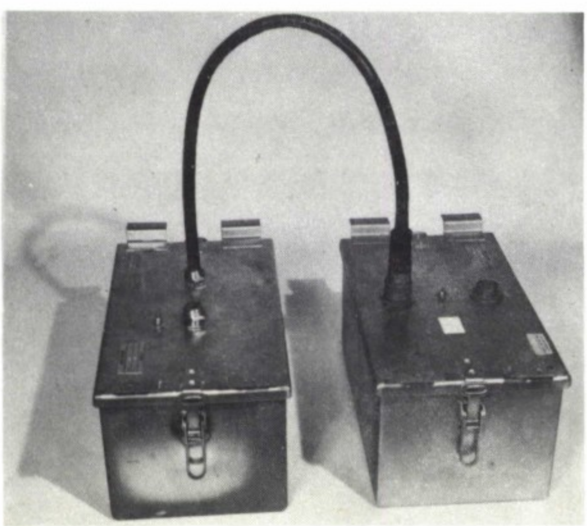


Figure 9. 7 Connection JA to JB

The cable termination boxes are of two types. Box JB (Figure 9. 5) will terminate a six-pair array cable, Box JC (Figure 9. 6) will terminate a 12-pair cable, serve as a branching point for two outgoing six-pair cables, and at the same time provide for connection of a local amplifier box.

The connection of the amplifier box to the cable termination box is by means of a 60 cm long cable which is wired permanently to the cable termination box, as shown in Figure 9. 7.

The data circuit

The data circuit (Figure 9. 8) originates in the 50 kohm data coil of the seismometer. In the JA box it enters the damping network. The damping consists of a 240 kohm resistor in shunt across the data pair; no individual correction of seismometer internal damping has been provided at this stage. Facilities have been prepared for inclusion of an attenuator on the input card.

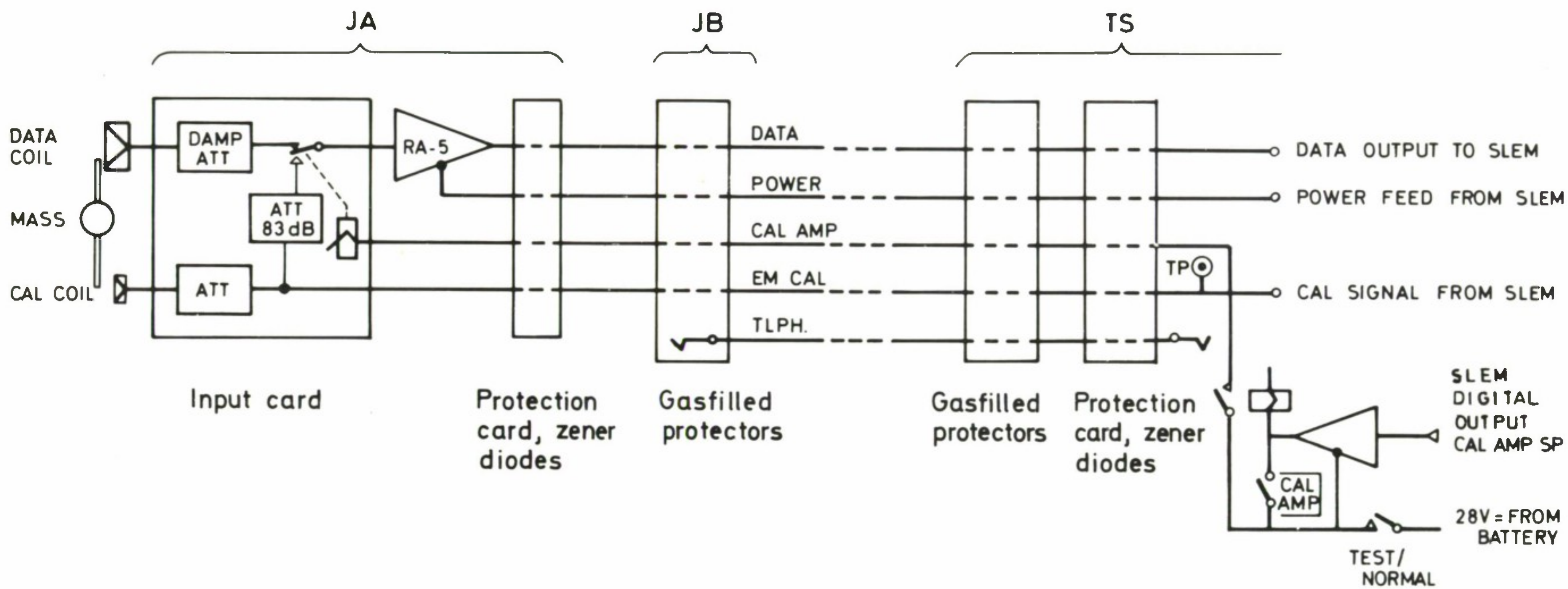


Figure 9.8 SP circuits and controls

The data signal is fed to the RA-5 amplifier (Figure 9. 4) via the cal amp relay, where the data signal can be replaced by a 1.5 mV pp calibration signal, derived through an 82. 6 dB attenuator from a 20 V pp cal voltage. The amplification of the RA-5 is set to 7070 or 77 dB.

From the output of the amplifier the data are fed through

- a protection card in JA
- gas-filled protectors in JB
- cable
- gas-filled protectors in the TS cubicle and
- SP protection cards in TS to
- output terminals for interfacing with the SLEM

The data signals are not subject to any intentional conditioning along this route, except that the amplifier output resistance, the cable resistance, and the protector resistors form a voltage divider with the load.

The EM cal circuit

The EM cal signal will normally be supplied by the SLEM and is standardized on 20 V pp for sinusoidal signals of frequency 1 Hz. The signals enter (Figure 9. 8) the TS cubicle on a terminal strip B, terminals 11 and 12, where individual cal circuits are parallelled; but are fed via test points (TP) in the local control panel. The current test points U1 and U2 should normally be bridged by a resistor equal to the impedance of the meter used. The parallelling of the cal circuit is arranged so that it is feasible to subdivide the circuit in the event of fault. The sequence of protection divices between the TS cubicle and the JA box in the WHV equals the one for the data circuit.

On the JA input card the calibration signal is branched in two directions: one is to the 82. 6 dB attenuator (see "The data circuit") and the other to an attenuator converting the 20 V pp signal to 400 μA current by a 2 x 25 kohm balanced network. This current is fed to the cal coil of the seismometer and will nominally produce a 12. 8 μN (1. 3 milligram pound) pp (sinusoidal, 1 Hz) driving force acting on the moving system.

The cal amp circuit

The idea behind the cal amp facility is described in the two previous paragraphs.

The cal amp circuit is the energizing circuit for the cal amp relays in the JA boxes, and is common for the whole subarray. The voltage applied to the cal amp circuit is taken from a 28 V no-break battery supply and is applied to all cal amp relays simulteneously when:

a) the test-normal switch is in "Test" and the "Cal Amp" switch in "Cal Amp" position, or

b) SLEM digital outputs for "Test" and "Cal Amp" are present.

Each relay draws approximately 5 mA and switches at approximately 10 volts.

The cal amp circuit has the same protective facilities as the data circuit with gas-filled protectors at the cable terminations in the TS cubicle and in the JB (or JC) boxes, and zener diode protection on circuit cards in TS and in the JA boxes.

The SP power supply circuit

40 V dc power for the RA-5 amplifiers is supplied by the SLEM (Figure 9.8) and enters the TS cubicle at terminals B7 and B8. The negative pole of the supply is offset - 2.5 V from ground by a voltage divider consisting of a 300 ohm resistor in series with a bank of diodes (Figure 9.9). This is done to nullify the potential difference between ground at the amplifier and the negative lead, which is connected to the inner case ground in the seismometer. The voltage drop along the cable will depend upon its length, and to compensate for different lengths, resistors may be inserted in the negative lead between the protection card and the gas-filled protectors. These resistors are determined individually.

The power circuit has the same protection facilities as the other circuits except that the zener diodes on the protection card have unbalanced layout - the minus lead does not have series resistors or chokes.

In the 6-pair cables, two pairs in parallel are used for power, in the 12-pair cables four pairs are used. The parallelling to reduce the voltage drop is not always necessary and may be regarded as an operating spare.

At the well head vault the voltage drops to 18 V and is stabilized by a resistance zener diode voltage divider.

The drain of each power circuit is approximately 30 mA.

Figure 9.9 shows the grounding system of the SP sensor chain. This design was copied from the LASA installation. The interference from high tension, 50 Hz overhead lines of the public power distribution network proved, however, to be much more severe in some of the NORSAR subarrays than anywhere in LASA. (Steps taken to improve the situation at sub-standard subarray branches will be described in the final installation report.)

The telephone circuit

The telephone circuit (Figure 9.8) is exclusive for each well head vault in order to act as a spare data pair as well as to facilitate SP systems checking in the field. In the TS cubicle each telephone pair is terminated in a jack, a common built-in telephone set may be plugged into any telephone circuit and extended to the public telephone system. The telephone pairs are protected by gas-filled protectors only. At the well head vault the pair terminates in a jack, inside the JB (JC) box.

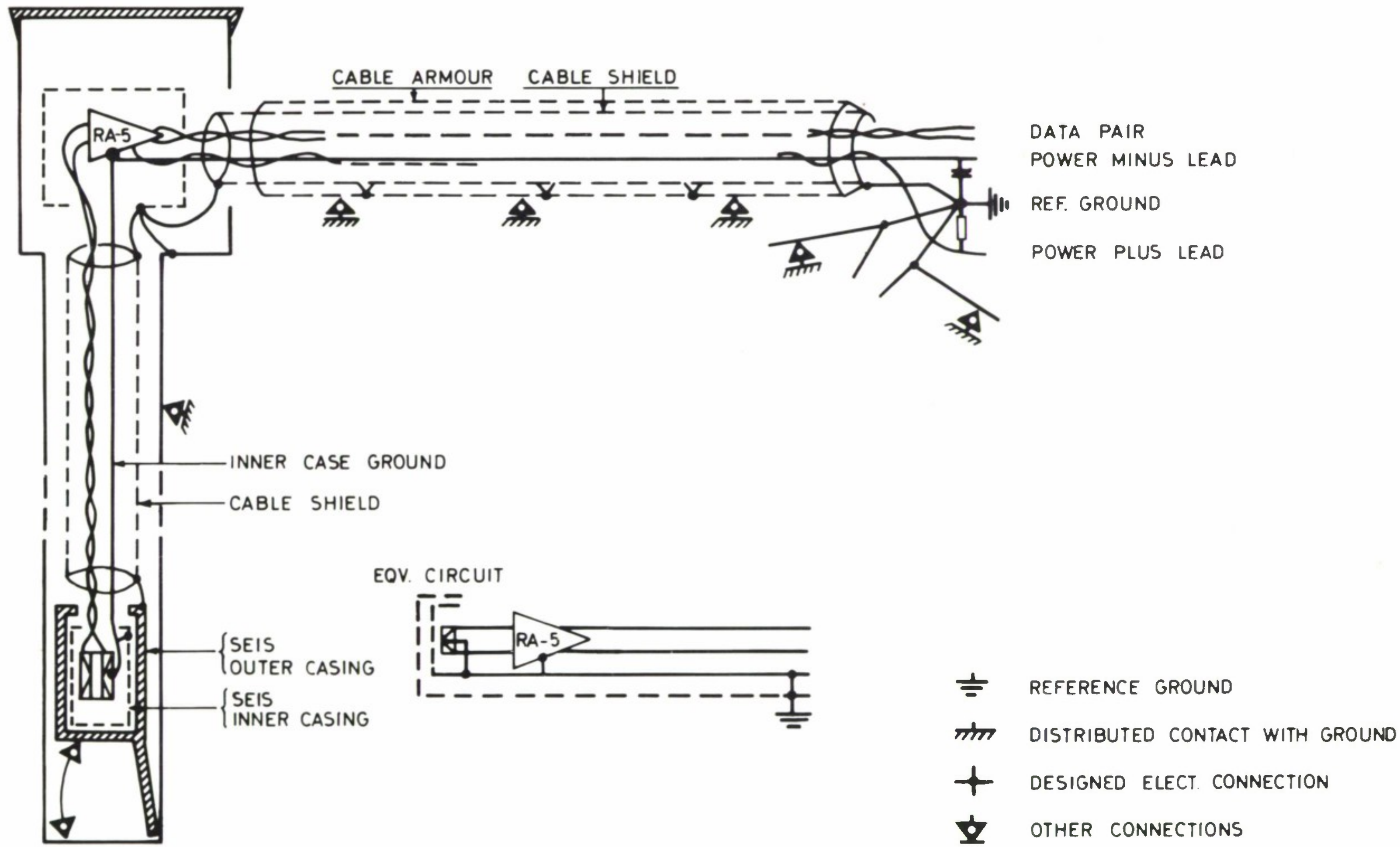


Figure 9.9 SP system grounding

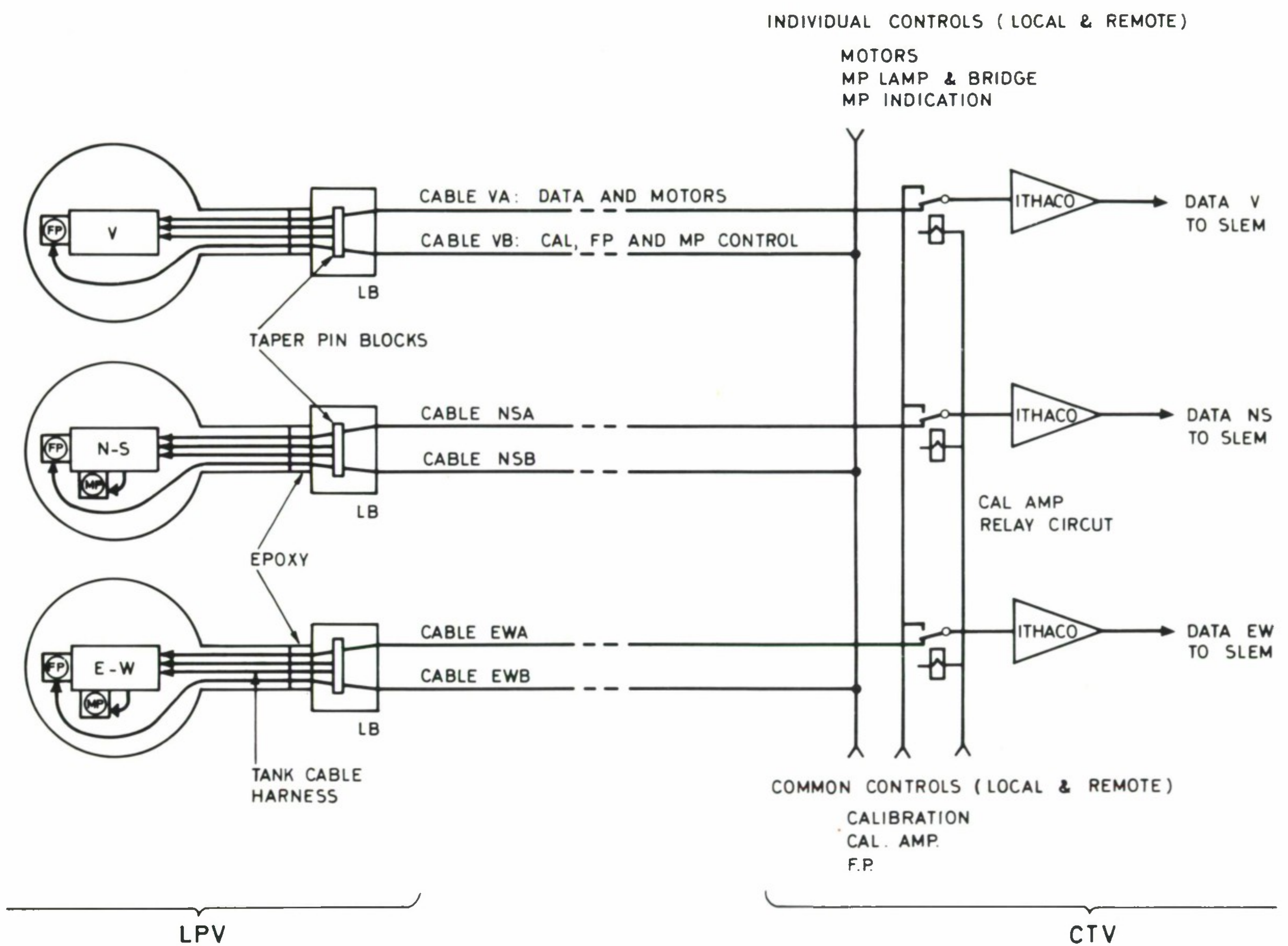


Figure 9.10 The LP circuits, simplified

9.3.2 The LP system

The general layout of the LP circuits is shown in Figure 9.10. The three seismometers V, NS and EW are each connected by a prefabricated cable harness to a separate LB termination box (Figure 9.11) which is mounted right on top of the entrance tube to the instrument tank (Figure 9.12). The cable harness has an airtight epoxy cast entry into the LB box and, in conjunction with this, a gasketed flange which is bolted to the flange of the entrance tube.

By placing auxiliary components (free period relay, mass position bridge adjustment, calibration adjustment network) inside the termination box, the only external signal cabling needed to be done in the vault is the termination of two cables (designated A and B) to the CTV from the taper pin blocks of each termination box. These cables are seen bearing to the left in Figure 9.13. It will be noted that no sealing of the cable itself has been done. This could be omitted because the cable used was filled with petroleum jelly. Cable A has pairs for data and motors - these may share one cable since the data will be of no use anyway when the mechanical suspension is shifted by the running motor - and cable B contains the other control circuit.

(In addition to the LP instruments an SP instrument has been placed in the LPV as seen to the right in Figure 9.13. The JA and JB boxes are mounted on a shelf, and a mounting plate with levelling screws holds the seismometer on a threaded gland.)

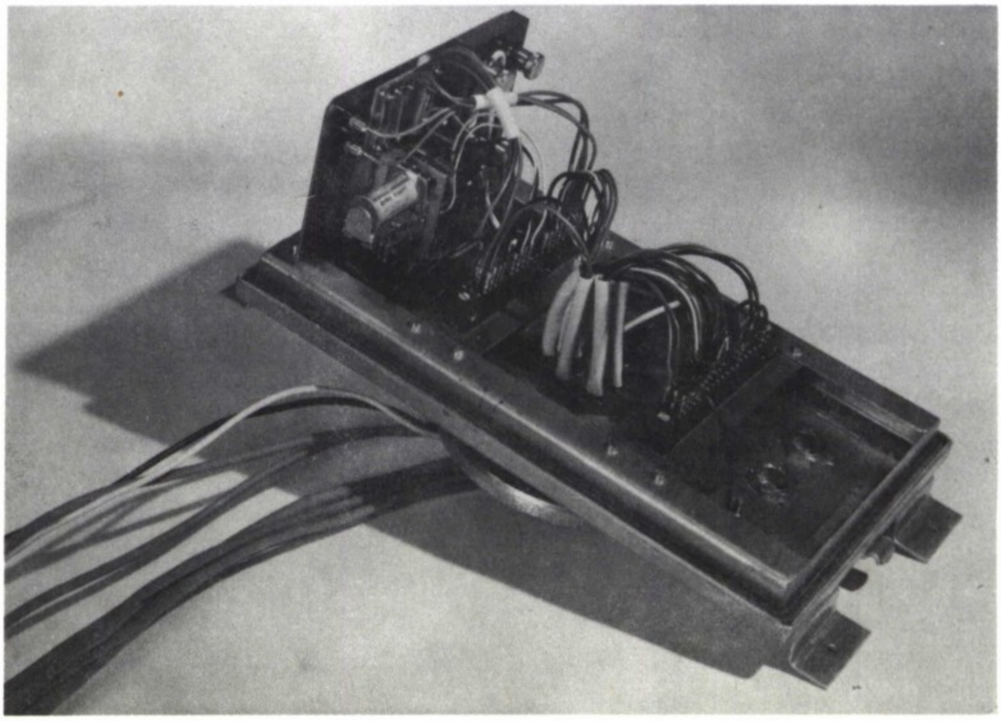


Figure 9.11 LB box, lid removed
(Epoxy entrance seal and flange visible in the middle, between taper pin blocks)

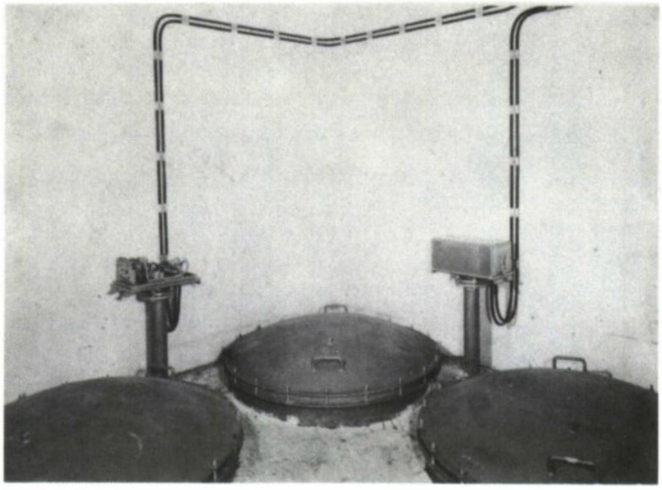


Figure 9.12 LP seismometer tanks (closed) with LB boxes and cabling
Entrance tube and LB box of seismometer tank to the right is not visible.

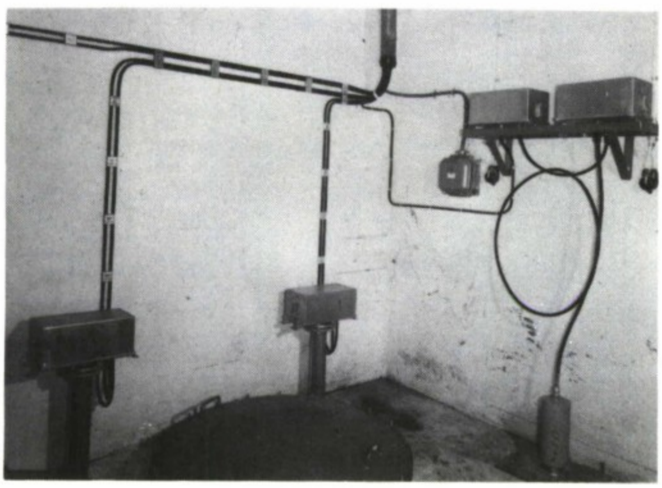


Figure 9.13 LPV cabling
SP seismometer with electronics to the right.

At the CTV the cable pairs are run via gas-filled protectors to their respective destinations. Special high voltage protectors are used in the motor circuits because of the 115 V ac supply.

The circuits for calibration, calibration of amplifiers, and removal of damping from the seismometers (FP - free period) are connected so as to enable simultaneous control of all seismometers from the TS cubicle (locally in the CTV or remotely from KCIN. The other circuits (motors, lamp and bridge feed) are handled individually for each seismometer.

The circuits for the three seismometers are identical as far as cable harness, cables and termination in the TS cubicle are concerned. There are minor differences in the connection to the seismometers; the vertical seismometer has an internal mass position (MP) motor and the convention for the mass position correction necessitates a pole reversal.

Signal conditioning and control of one seismometer (Figure 9.14) is described below.

The remote control is effected by digital outputs 1 to 20 from the SLEM. Since the power handling capacity of the SLEM output contacts is limited, a one stage bit amplifier has been inserted to reduce the load. In the code converter for the motor control circuits this buffering is provided by the logic circuitry and no separate bit amplifiers are provided. The presence of a bit is defined by closure of a contact.

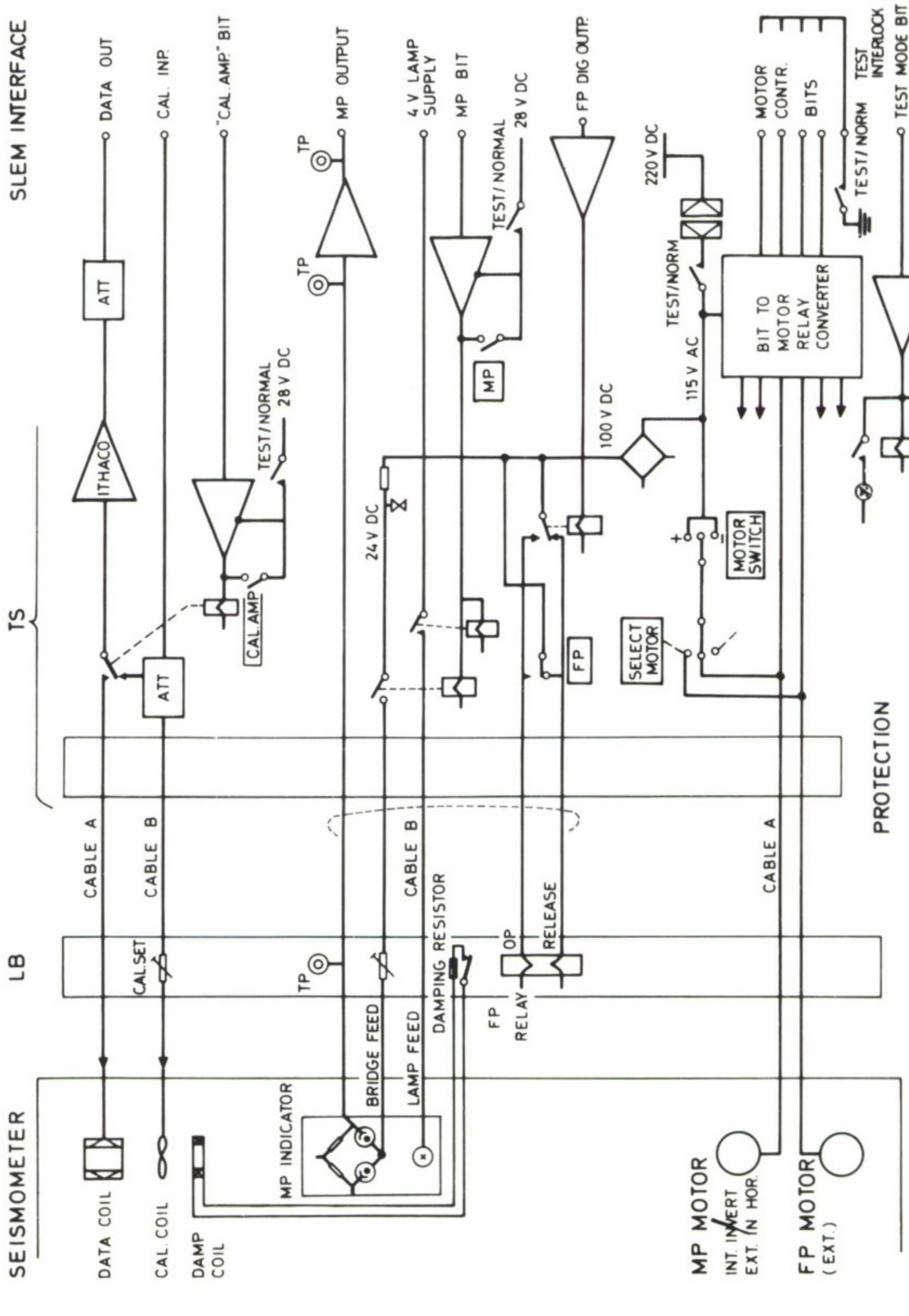


Figure 9.14 LP circuits

The LP data circuit

The data circuit originates in the 50 kohm data coil and is taken on a separate screened pair to the LB-box taper pin block, where it is connected straight through to the red/blue data pair in cable A. The same colors are used throughout the circuit.

In the TS cubicle the cable is terminated on gas-filled protectors and from there fed via 8.2 kohm resistors to the cal amp card, which contains relays that can substitute the signals from the seismometers by a 4 mV pp calibration voltage as input to the amplifiers (Itacho model 6083-82).

From the relay cards the signals are fed to the amplifiers from which the outputs go to an attenuator card, where the 60 V pp output voltage at full dynamic range from the amplifier may be scaled to the input voltage of the analogue to digital converter (in the SLEM). At present the attenuator is set at 4.28 to 1, or 10.6 dB.

The output from the data channels is available on the terminal strip B:

Vertical data	B27 + B28 -
NS data	B29 + B30 -
EW data	B31 + B32 -

The EM calibration circuit

This cal signal is supplied by the SLEM and enters the TS cubicle on terminals B25 (+) and B26 (-). The signal is either a 20 V pp 0.04 Hz sine wave or a square wave. Below, it is only described as a sine wave at the stated level.

The cal signal is routed two ways:

a) To the cal amp card where it is applied to a 74 dB attenuator giving 4 mV pp at the output. The output impedance is 60 kohm and simulates the normal source impedance which comprises series protection resistors in addition to the data coil resistance.

   The function is described in the previous section.

b) Through a 50 kohm resistance network to all three calibration coils in series, the series connection being done at the gas-filled protectors. The resistance network is divided between the two leads to keep reasonably symmetry and a variable 10-kohm resistor is included for setting the current in the cal circuit to 450 μA pp. Facilities are available for measuring this current on the front of the local control panel (remove a jumper).

In each seismometer circuit is included a current divider consisting of a 20 ohm resistor in series with the calibration coil and a variable resistor network in shunt across the combination. This cal set network is used in standardising the effective motor constant of the calibration coil, by referencing the force on the mass to the current in the cal circuit instead of in the coil itself. The value selected is G_c = 0.0280 N/A.

The cal amp circuit

The cal amp circuit is used to energise the relays that switch the amplifier away from the seismometer and on to a standardised signal, as described in the section on the data circuit. The energising voltage is 28 volts dc from the no-break battery supply and will be applied when the LP cal amp switch on the local control panel is operated. It will also be energised if an LP cal amp signal is presented by the SLEM. Both ways of operation are conditioned by test mode, i e the Test/Normal switch on the local control panel must be thrown to position Test, or a bit must be present at the Test digital output of the SLEM.

The MP (mass position) indicator circuit

This circuit produces a signal, the sign and amplitude of which indicates the position of the seismometer mass relative to a reference center. The mass position indicator derives its signal from a photocell bridge. The bridge is fed by a separate circuit supplying 22.5 V dc derived from a rectifier that also supplies the so-called free period relays (see next section).

The rectifier will only work when ac mains are available.

The bridge feed voltage may be adjusted in the LB box by a series resistor and the output from the bridge may be monitored by a high impedance meter at test points (TP, figure 9.14). The load impedance is 10 kohm and the maximum current is $50 \mu A$ corresponding to a 5 mm deflection of the mass. Voltage (4 V) to the photocell bridge lamps is supplied from a separate voltage stabilised rectifier.

Both lamp and bridge feed voltages are normally disconnected and will only be applied when selected by the appropriate switch on the local control panel or the right digital signal from the SLEM system, both ways being conditioned by the test mode. The mass position indicator output in the TS cubicle is ± 0.5 V max across 10 kohms. This output is amplified to ± 5 V max in the MP converter to match the input requirements of the SLEM. Test points are provided on both the input and output side of this converter.

The FP (free period) circuit

The free-period circuit consists of a latching relay (in the LB box) that opens the circuit of the damping coil when voltage is applied to Operate coil. The looped damping circuit with damping resistor closes when voltage is applied to the Release coil. The operating voltage, 100 V dc, is derived from a rectifier fed from the mains. It is therefore not possible to remove damping and measure free period when the CTV is operating from the no-break battery.

Voltage to the FP relay coils is conditioned by test mode and may be operated from a spring loaded, normally neutral, three-way switch on the local control panel, or by the presence of an FP digital output from the SLEM.

When the circuits change from test mode to normal mode, a delay in the applied power will provide a release pulse for the FP relay.

The motor circuits

Each seismometer assembly is fitted with two motors, one for controlling mass position, the other for controlling free period. Voltages for the motors are 115 V ac, derived from the mains through an isolating transformer, and control is thus not available if the installation is run on the battery.

Voltage to the motor may be applied manually from the local control panel by a two-switch combination: one six-position motor selector and one spring-loaded, normally open, three-position lever switch, which selects the sense of rotation. Single-phase asynchronous motors are used, the auxiliary phase is fed through a series capacitor. The capacitor is switched by applying voltage between the common point of the two-motor windings and one or the other of the outer terminals. In the cable between CTV and LPV two pairs are used for each motor, two conductors, one from each pair, is parallelled for the common

In the remote control mode, a group of four digital outputs, each representing one bit, will select motor and sense of rotation by means of a code translator. The first two bits select the seismometer that is going to be controlled, 01 will enable control of the vertical, 10 of the NS and 11 of the EW seismometer. The next bit will decide whether free period (0) or mass position (1) is to be controlled. The last bit determines the sense of rotation of the motor. When the first two digits are both 0, all motors will be at rest.

The motor circuits are protected against unintended operation by the Test/Normal switch, which must be in the Test position. In remote control the test mode must be called up by transmission of the appropriate Test digital output. If test condition is selected locally, remote operation of motors will not be possible due to an interlock.

A 10-ohm shunt is inserted in the common lead of the motor supply circuit and the shunt terminals are brought to the front of the local control panel for measurement of motor current.

The LP grounding system

The armour and shields of the cables between the CTV and the LPV are connected to the common reference ground of the TS cubicle. In the LPV this ground is connected to the instrument tank and the chasses of the LB junction box.

Signal ground also originates in the TS cubicle and is connected via the gas protectors, which are not operative in this circuit but only serve as terminating points for the ground cable. The grey/white pair of cable A takes the ground to taper pin block in LB, and here it is distributed to several points of taper pin blocks A and B.

Individual cables in the cable harness to the seismometers have their shields connected at the taper pin blocks. At the other end the shields are not connected. The housing of the seismometer is connected to ground via pin G on the monitor plug and the grey-white pair in the monitor cable.

9.3.3 The no-break power supply

The no-break power supply consists of a 320 Ah Ni-Cd storage battery with 21 cells and a controlled charger (Figure 7.3). The nominal voltage of the battery is 28 V, and the control circuits are designed to keep the voltage within the limits 24 to 32 V without harmful gassing. Motor control, FP actuation, MP lamp supply and bridge feed are supplied from the ac mains and will not be operative during a mains failure.

During normal operation with mains present the maintenance change and the load current are supplied at a nominal voltage 29.4 V. This voltage is adjustable: a high setting will increase the available capacity of the battery at the expense of increased gassing and loss of water. A low setting will reduce the available capacity below 85% of stated rating or 270 Ah, which is the expected capacity at 29.4 V.

Following a mains interruption period with battery discharge, the charging process will be current controlled to 40 A in the initial phase until 32.5 V is sensed across the battery, then it will change to voltage control at this voltage. The current will gradually decrease and when a charging rate of approximately 10 A is reached, indicating that the battery is approaching the fully charged condition, the voltage is switched back to the maintenance charge at the lower voltage (29.4 V). The purpose of this arrangement is to recover the capacity of the battery as quickly as possible after it has been tapped.

As an additional safeguard, in case the current sensing should fail to recognise that the battery is approaching the fully charged condition, a timer will effect the change-over to the maintenance voltage. The timer is adjustable; a reasonable setting should be 12 hours.

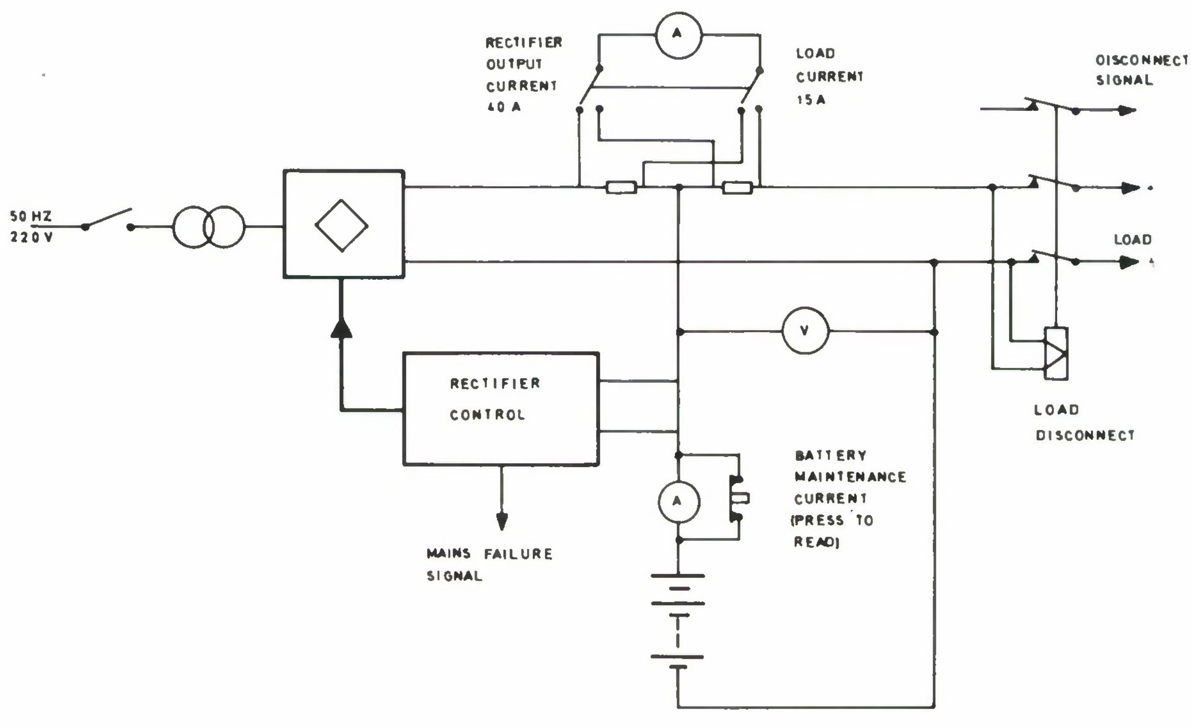


Figure 9.15 <u>No-break power supply, simplified</u>

If the mains failure lasts longer than the available capacity of the battery, the load will be disconnected when the battery voltage goes below 24 V. In order to be safeguarded against instability, the reconnection of the load will not be effected until the voltage has risen to 28 V.

Mains failure and load disconnection indicators are available at discrete outputs for remote transmission; the latter has a delay circuit that ensures that it will be possible to transmit the message before the SLEM is disconnected.

The arrangement of the measuring facilities and the origin of the remote supervisory signals can be seen from a simplified schematic diagram, Figure 9.15.

9.3.4 Physical layout of the TS cubicle

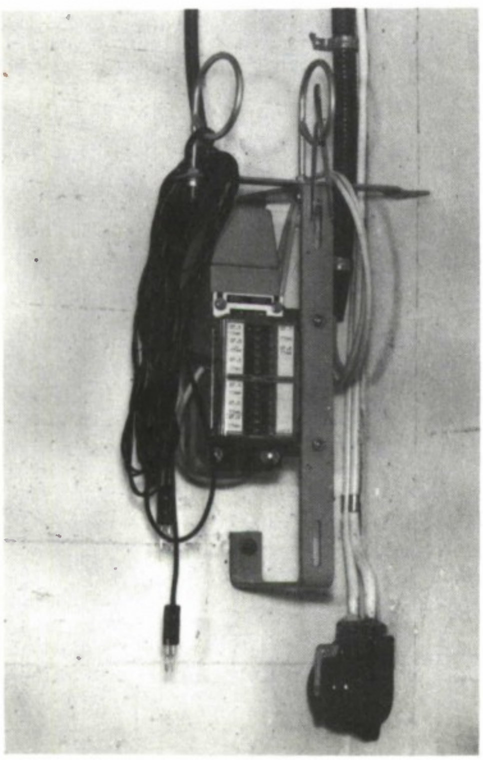


Figure 9.16 NTA standard cable head (in CTV)

In the CTV all terminations of signals are taken to the TS cubicle which is shown in Figure 9.1. All cables enter the cubicle on top. The array ground cables have their armour and corrosion protection removed at the vault entrance and go directly to the TS cubicle. The NTA communication cable is taken to their standard cable head as shown in Figure 9.16 and by a screened installation cable into the TS cubicle.

The TS cubicle is subdivided into panels and shelves, with all the internal cabling prewired in plastic box conduits. Identification of the different parts is possible from Figures 9.17 and 9.18, showing the TS cubicle from front and rear.

10 OTHER TASKS

The previous chapters deal with the major task specified in contract F61052-68-C-0060, viz the NORSAR field installations. Below are presented brief accounts of the implementation of other tasks stipulated in the contract. The reporting is generally done in a summary way, for one or more of the following reasons:

- The main efforts of the task fall outside the period of time covered by this report; a more comprehensive account will be given in the Final Technical Report.
- An agency other than NDRE is the main or sole contractor for the job; the agency concerned reports directly to ESD.

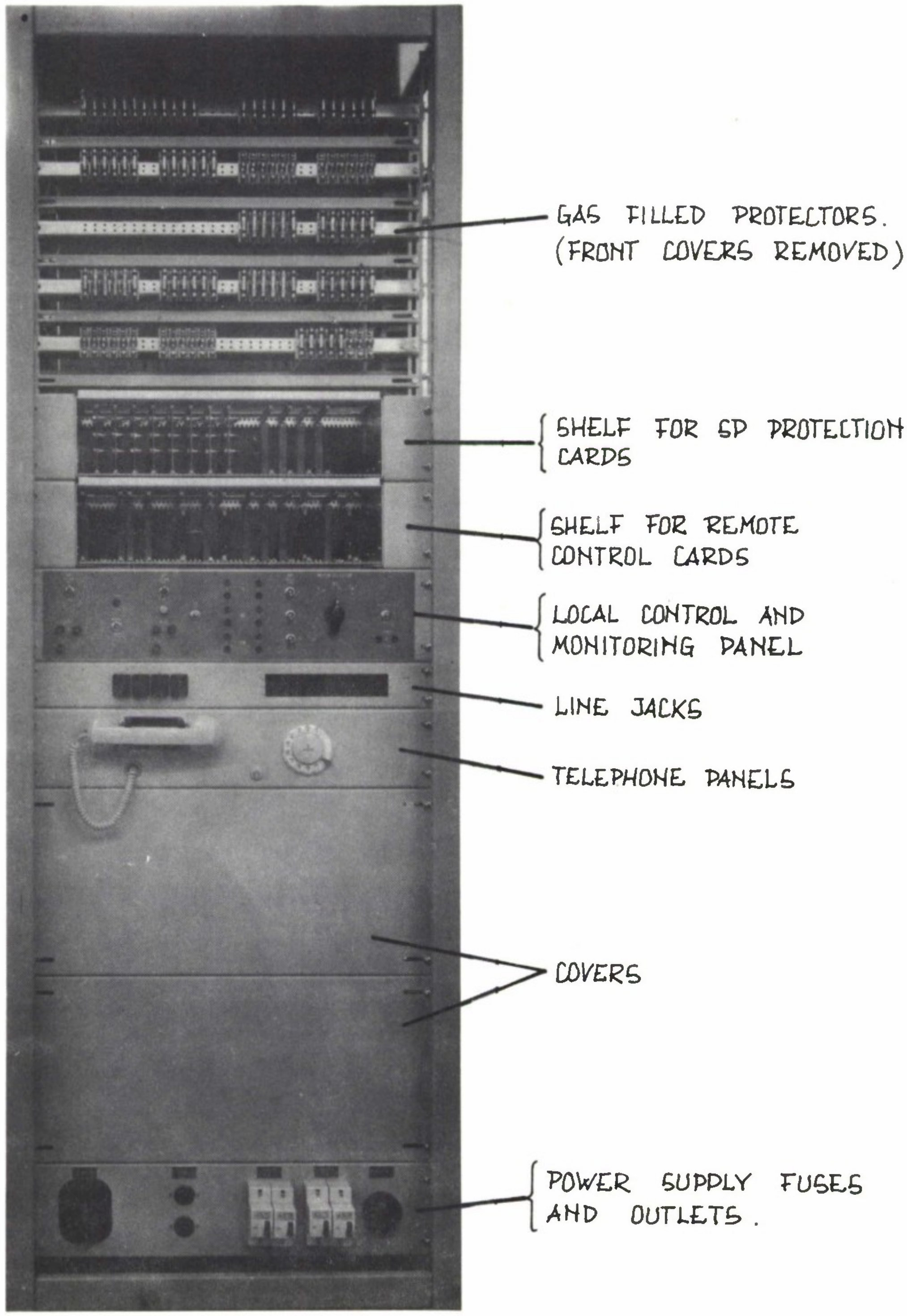


Figure 9.17 TS cubicle, front view

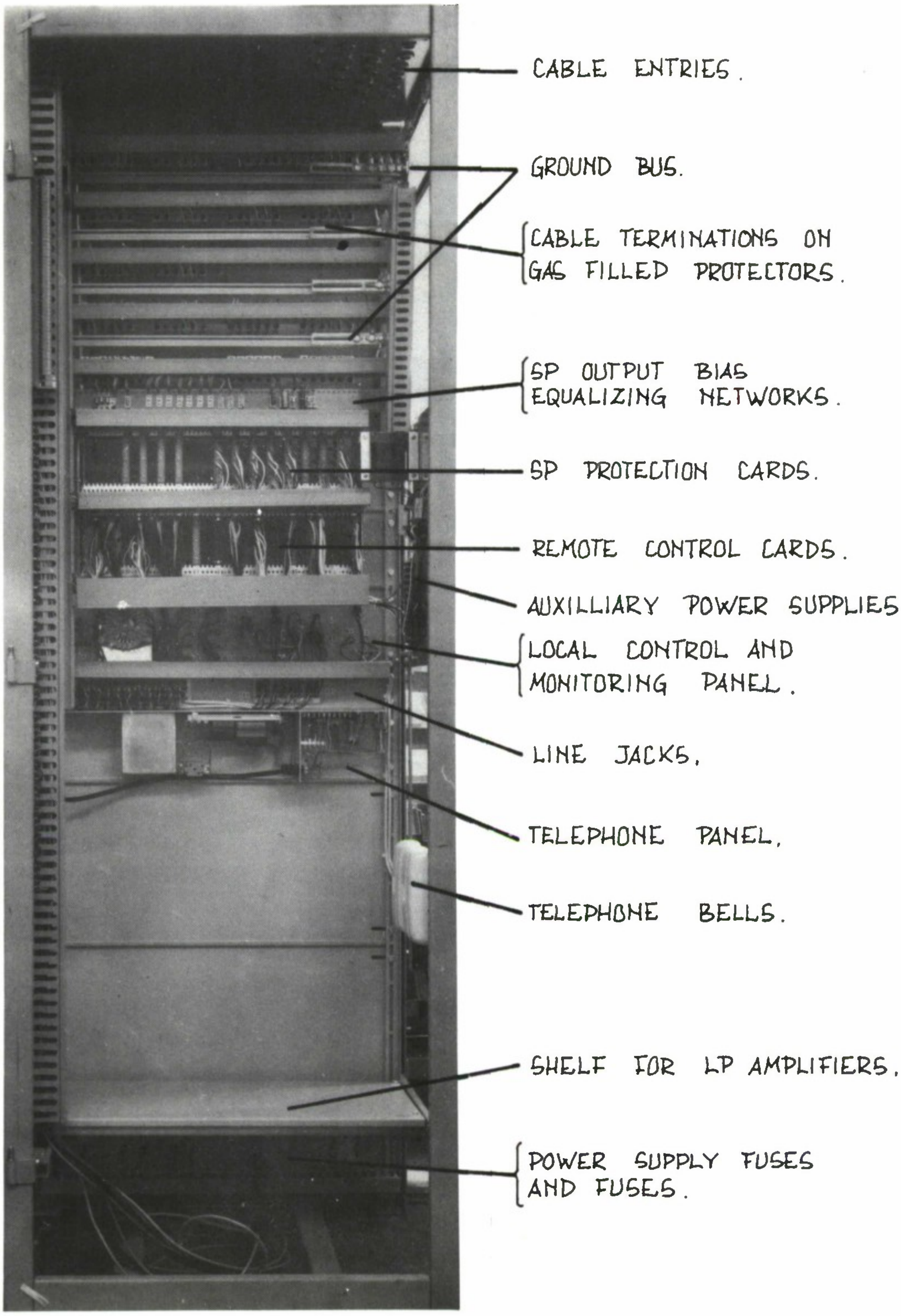


Figure 9.18 TS cubicle, rear view

- The installation part of the job is the less important one, the main effort is operation of-a field subsystem in support of special scientific/technical studies; full reporting is done elsewhere, e g in O & M reports.

10.1 LP noise study

In the beginning of October 1968 NDRE was asked by ARPA (via ESD) to provide for on-site recording of LP data at a few A- and B-ring LP sites in the period 1 December 1968 through 31 May 1969. The immediate purpose was acquisition of data for further studies of the regional seismic characteristics in the LP band, and the end objective to obtain the best possible basis for finalization of the large array design. Equipment of the Phase 1 monitoring system was to be used for the recording, and the procedures for the monitoring were to be identical to those used at Trysil and Falldalen (see Final Technical Report, NORSAR Phase 1).

The subcontractor for O & M of the NORSAR field installations, Noratom-Norcontrol A/S, started removal and reinstallation of the LP DART recording equipment in October. The Falldalen installation (hut + DART recorder) was moved to site 06B03, the Trysil one to 07B01, while the Øyer (01C) DART was placed in a rented hut at 01A01.

The equipment was in place at all sites by early December, but it proved exceedingly difficult to obtain proper recording at all sites simultaneously. A series of component failures, most of them probably caused by the transport to the sites, prevented useful recording far into 1969. Acceptable data acquisition over longer periods of time did not take place until February/March.

The tapes were sent to Lincoln Laboratories, MIT, who merged the data from the three synchronous tapes onto one tape and made the reformated tapes generally available through the LASA Data Service Center. The Earthquake Observatory of the University of Bergen was one of the customers.

Recordings ceased at the end of May 1969.

10.2 SP noise study

In the fall 1968 NDRE was asked by ESD to provide assistance for a small US technical group that was to perform special SP noise measurements at several of the A and B-ring subarrays during the first months of 1969. This investigation constituted a continuation of the noise studies at the Falldalen site of the Phase 1 installation. The main objective was to find out whether it was justified to use shallow (surface) holes instead of deep boreholes at sites with rock outcrops. The measuring techniques would comprise correlation between signals from SP seismometers in the 60 m boreholes and those in the adjacent LPVs, and also between sensors up to 8 km apart.

The group came from the Earthquake Mechanisms Laboratory (EML) of the Environmental Science Services Agency (ESSA) and consisted of a leader, Mr J Murdock, and two technicians. They arrived during the last days of 1968, started measurements in the field in week 2 (6 - 10 Jan) of 1969, and completed the work in the first

days of April. During that period recordings had been performed at all the subarrays of the A and B ring. Assistance to the group was rendered by personnel from Noratom-Norcontrol A/S, the field O & M contractor, and from Norconsult A/S, the main consultant.

10.3 Special SEM installation at Øyer (01C)

The Øyer installation was scheduled for parallel operation with tape recordings and remote transmission of data to KCIN during the summer 1968. It was not realistic to implement the SEM interface for this subarray within the same frame as for the subarrays under construction in the 1968 program - it would in any case have come out as an odd version with non-standard components, and it would obviously have delayed both the regular program and the Øyer installation since it could not have been started before the subcontract was signed.

The implementation was effected by Norconsult personnel using partly the circuitry of the tape recording station (Phase 1) interface, partly circuits from a control rack supplied from Montana, complemented by additional circuits of Norconsult design. Except for the use of non-standard components and layout the design was kept as close as possible to the system that was to be contracted, and served the useful purpose of testing the design. Even though the completion was delayed in relation to the initial schedule, so was the SEM and no extra delay was introduced.

10.4 The NORSAR Data Processing Center

Two main alternatives for location of the NORSAR Data Processing Center (DPC) were brought up during the US - Norwegian discussions fall/winter 1967/68.

Placing the DPC near the geographical center of the array (say in the town of Hamar) would minimise and probably also simplify the telecommunications system. This would certainly reduce the annual cost of renting lines from NTA and probably increase the reliability of the system.

If located near Oslo it would profit from a local background very much stronger both technically (maintenance of data handling equipment) and scientifically (computer software, seismology).

The decision taken spring 1968 was in favour of the latter alternative, and stipulated that the DPC should be placed at Kjeller, some 20 km E of Oslo, taking advantage of facilities and competence available at the Kjeller Computer Installation (KCIN), an institution owned by and located adjacent to NDRE, the Institute of Atomic Energy (IFA) and the Norwegian Air Force Support Command (LFK).

KCIN participation in the NORSAR activities started with preparation for a temporary DPC installation in existing facilities, planning of permanent quarters for the DPC and for staff acquisitions. Mr S A Øvergaard, head of KCIN, visited Washington in April 1968 to discuss preparations and future plans with SAAC.

Temporary facilities for computer equipment were available by 1 July. Installation of an IBM 360/40 took place in early August and software testing could start. A programming detachment of SAAC and IBM Oslo personnel started work at KCIN on 8 August.

Prefabricated office facilities for NORSAR DPC personnel became available in December.

Additional computer equipment was installed during the last months of 1968. Spacing and air-conditioning capacity proved sufficient for the temporary installations.

A supervisor of daily computer operations and the necessary staff of operators were recruited and started training in August under the direction of a system supervisor (O Steinert) who joined the NORSAR group on 1 July. Operators attended IBM courses, were introduced to problems of detection seismology and given on-the-spot training when the computer started operation. Two-shift runs with SEM test programs and testing of the on-line system started in November 1968.

Acquisition of scientific personnel was delayed. A senior seismologist (E S Husebye) and a mathematician (F Ringdal) started working at KCIN at the end of 1968. Husebye visited SAAC in November 1968 while still in the US.

11 CONCLUDING REMARKS

The present report does in certain respects go beyond the formal time frame given by the calendar year 1968. This is not in conflict with the title of the report, however, since the 1968 installation program customarily is defined as the installation of the subarrays 01A and 01B through 07B, i e that part of the Phase 2 installations scheduled for completion in 1968.

The bulk of the construction work of this program was indeed completed in 1968. The combination of a late start (1.2) and delays due to technical problems (4.4, 6.2) prevented full completion before winter conditions advanced, and some landscaping and backfilling had to be postponed until early summer 1969.

The field instrumentation by Siemens and checkout by the consultant were originally planned to be finished by the middle of December. However, this part of the job proved to be much more time-consuming than anticipated. In fact, some minor details were not ready until July/August 1969. Some explanation should be given for this delay; a few of the reasons are listed below:

- Delivery time of certain vital components from W Germany proved to be exceptionally long.
- Construction details failed, and new materials or procedures had to be found, e g a potted seal in the LB box cracked, probably due to very low temperatures during installation, and a search for better compounds had to be initiated.
- A number of SP and LP seismometers proved to be faulty. Procedures for sorting out good ones had to be devised, or modified parts had to be reordered from USA.
- A few earth cable faults were discovered during the installations, and time was spent localizing the repairing these.

- Excessive 50 Hz noise from commercial high tension lines was encountered at a couple of the subarrays. Eventually one had to accept the noise for the time being and leave the search for a solution to the problem to a later date. In the meantime much effort had been spent trying to suppress the noise.

- It became obvious quite early that the SLEMs would not be delivered until late 69/early 70, nor would the modems be available for a long time. Under these circumstances ESD and NDRE agreed that no urgency existed that made it necessary to step up the effort drastically in an attempt to keep the original schedule. It would be more economical to keep the efforts at the proposed level and prolong the installation period.

It should be emphasized that the present report, even if recording the installation of only eight out of the 21 subarrays of Phase 2, in fact covers the major part of the standard procedures and installation types of the total Phase 2 effort. Consequently, the Final Technical Report will rest on and refer to the present report to a very large degree.

References

(1) - Final Technical Report, NORSAR Phase 1, Intern rapport S-37, Norwegian Defence Research Establishment (1968)

(2) - NORSAR Array Design, preliminary report SAAC, IBM Corp, 6 March 1968

APPENDIX 1

LAND LEASE AND DAMAGE COMPENSATION - AGREEMENT FORM
Authorized translation from Norwegian original:

AGREEMENT

The Norwegian State represented by the Ministry of Defence, hereinafter called the State, and .... as owner of estate No , lot No , in .... municipality, hereinafter called the Landowner, have concluded the following agreement concerning a projected seismic installation which will affect the above property:

1 In this connection the Landowner transfers to the State the following perpetual rights:

a) The right to maintain a cable in a trench along a route to be agreed on.

b) The right to install and maintain a seismic measuring station in two concrete cellars 3.5 m x 3.5 m and one 60 m deep drill hole with a diameter of 35 cm.

c) The right to install and maintain a seismic measurement point in a room 1 m x 1 m over a drill hole having a depth of up to 20 m and a diameter of up to 25 cm. (If letters b and c are not relevant, delete when signing the contract.)

The Landowner retains title to the affected areas. Accurate map or photograph of the installation on the Landowner's property shall be attached as an appendix to this agreement.

The State has the right to transfer its rights hereunder.

2 The State is permitted to start construction work at not less than eight days notice to the Landowner after the latter has been informed of the installation's location in the field on his property. The State thereafter has the right to:

a) Plan and mark the trench line, clear same to the necessary width and undertake excavation and blasting of trenches, laying lines, filling the clearing.

b) Carry out any construction work including drilling in connection with the station mentioned in point 1 above, for the properties where this is relevant.

c) Subject to the requirement of normal care, to utilize the Landowner's roads and terrain for transportation and to store construction material while the work is in progress, both during the construction period and during the subsequent operation of the installation.

3 After the above mentioned work has been performed, the Landowner shall have the right to utilize his property in every way as before, except that:

a) No installation must be constructed in such vicinity of the cable route as to cause physical damage to the cable.
If future utilization of the Landowner's property for agricultural or forestry purposes necessitates rerouting of the cable, the costs of such work will be charged to the State alone.
The Landowner is however obliged to notify the Defence Research Institute at Kjeller before the work commences, at least two months in advance, and only during the period April 1 - September 1.

b) At each measurement station, two concrete cellars of 3.5 m x 3.5 m will be constructed. In an area of 100 m by 100 m round each cellar, any building or installation which can cause vibration in the ground must not be constructed.

c) In a square of 50 m by 50 m round the measurement points, any building or installation which can cause vibration in the ground must not be constructed. The Landowner shall continue to have a right to transport timber in the terrain or along existing roads at a distance of not less than 15 m from the cellar walls or measurement points. If the Landowner intends to undertake any activity within the 100 m square or 50 m square mentioned in points b and c above which may cause vibration in the ground, for example timber cutting or removal, he is obliged to give three days advance notice thereof to the Defence Research Institute at Kjeller.

4 For his surrender of land and land rights, loss and inconvenience in connection with the preparatory work and the construction work, the Landowner shall receive full compensation which, failing amicable agreement, will be stipulated by judicial valuation, cf § 4 of the Judicial Valuation Act.

The parties agree that the District Forestry Superintendent for the municipality in which the property is located will assist in ascertaining the most suitable cable route, registering the forest which must be cut, and such other loss as occurs in consequence of the construction work.

If within six months from the date of completion of the construction work in the area .... in which his properties are located, the Landowner has failed to accept any compensation offer submitted by the State, the State is obliged without delay to present a request for valuation to the District Judge of Hadeland and Land.

The Landowner is entitled to 5% interest on the compensation amount which will be awarded to him, effective from date of signature of this contract.

5 Any loss occurring in connection with future repairs and inspection of the installation will be compensated in the same manner as described in point 4 above.

6 On the part of the State this agreement is concluded subject to the reservation that the State starts the construction work in the described area by January 1, 1971. If the installation is not constructed, the Landowner is entitled to compensation for such loss or inconvenience as the planning may have entailed.

7 The State has declared itself willing to pay necessary costs of technical and legal assistance for the Landowner in connection with the compensation, cf the rules of § 15 of the Expropriation Act and § 43 of the Judicial Valuation Act.

8 This agreement can be registered as an encumbrance on the Lnndowner's property. The costs thereof will be paid by the State.

This agreement has been issued in two identical copies, one to each party.

.... 1968 Oslo 1968

....

....

....

APPENDIX 2

CABLE SPECIFICATIONS

A2.1 General information

Two types of cable have been used for seismic signals transmission within the subarrays.

About 50 km 12-pair cable type STK A12-0.91 EWBP-52P was left over from the Phase 1 installations (Øyer subarray was not completed according to the original plans). The cable is based on US REA specifications PE-23, slightly modified.

The re-evaluation of array configuration in 1968 resulted in smaller subarrays which made use of 6-pair cables more economical. STK had in the meantime developed a cable filled with petroleum jelly. This design justified use of laminated sheath without impairing the moisture barrier, and reduced the price further to a level lower than any of the prices quoted by other sources. The petroleum jelly-filled 6-pair cable has type designation A6-.91 EYBA-52P and 400 km of this cable was ordered for completion of the 1968 program and most of the 1969 program.

Telecommunication cables linking the subarrays to the NTA network are all based on NTA specifications.

A2.2 STK type A12-0.91 EWBP-52P

Number of pairs	12
Conductors	0.91 mm Cu (19 AWG)
Insulation	0.375 mm PE
Inner mantle	1.3 mm PE, black (REA: 50 mils = 1.27 mm)
Shield	0.2 mm single coated aluminium/PE laminate + 1 mm^2 tinned, flat-rolled copper litz wire
Outer mantle	1 mm thick, black PE, laminated to shield (REA: 1.02 mm) Outer diameter 16.5 mm
Sheath	2 layers of galvanized band steel, 18 mm x 0.3 mm each
Corrosion protection	1.3 mm PVC, black
Outer diameter	20.5 mm
Colour code	1 Wh/Blue 2 Wh/Or 3 Wh/Green 4 Wh/Br 5 Wh/Grey 6 Red/Blue 7 Red/Or 8 Red/Green 9 Red/Br 10 Red/Grey 11 Black/Blue 12 Black/Or

A2.3 STK type A6-0.91 EYBA-52P

Number of pairs	6
Conductors	0.91 mm Cu
Insulation	0.375 mm PE, w/vaseline
Inner mantle	1.3 mm PE
Earth conductor	1 mm Cu
Shield	0.2 mm Al
Outer mantle	1 mm PE
Sheath	2 layers of 0.3 mm galvanized band steel
Corrosion production	Asphalt + jute
Outer diameter	19.8 mm

A2.4 Electrical specifications of the NTA cables

STK L8 - 0.9 EVBA - 45D (earth cable)

STK L8 - 0.9 EVWP - 45D (overhead cable)

a) The direct current loop resistance of 0.9 mm conductors shall not exceed 55 ohms per km, when corrected to a temperature of 20°C.

b) The insulation of a factory length shall withstand for two minutes without breakdown, a voltage of 2000 volts rms, 50 Hz, applied between all the conductors connected together and the earthed sheath.

c) The insulation resistance measured with a DC voltage of 500 volts between a conductor and all the other conductors connected together, and to the earthed sheath shall not be less than 10 000 ohms/km. The reading shall be made after electrification for one minute at a temperature of at least 15°C.

d) Leakance is measured between the two conductors of a pair, with an alternating current of 800 c/s, all the other conductors connected together and to the earthed sheath. The leakance constant for a pair shall not exceed 25. The leakance constant is the ratio conductance/effective capacity.

e) Effective capacity of a pair is measured between the two conductors, with an alternating current of 800 c/s, all the other conductors of the cable connected together, and to the earthed sheath.

The average effective capacity of all the pairs in a factory length shall not differ from the nominal value 37 nF/km by more than ± 5%.

In a factory length, the difference between the effective capacity of any pair and the average capacity for the cable length shall not exceed ± 12.5%.

f) For a factory length of 230 m, the capacity unbalances shall not exceed the values given in the table below:

	Average values pF	Maximum values pF
side - side	65	260
side - earth	250	1000
pair - pair		260

For lengths greater than 230 metres, the following rules are applied:

The average value of side - side shall be multiplied by the square root of the ratio between the length in question and 230 m.

All other values in the table shall be multiplied by the ratio between the length in question and 230 m.

APPENDIX 3

DATA CONCERNING THE COMMERCIAL POWER SUPPLIES

Subarray	Local power co	Length of line in km	No of phases	Voltages V
01A	Ringsaker & Nes Kraftanlæg	0	3	230
01B	- " -	0.5	3	230
02B	Åmot komm el verk	3.5	3	1000
03B	Løten komm el verk	1.2		1000
04B	Stange komm el verk	0.7	1	230
05B	Toten komm el verk	0.4	1	230
06B	Vest-Oppland komm Kraftselskap	0.8		230
07B	Gjøvik el verk	0.2		230

Table A3.1 <u>Data concerning commercial power supplies</u>

APPENDIX 4

LPV PRESSURE TESTS

Seismic noise may be introduced by rapid variations in the atmospheric pressure in the LP seismometers and their surroundings. This effect is reduced by stipulating maximum permissible equalization rates for the pressure differences instrument tank/LP vault, and LP vault/free atmosphere. The equalisation time constants (time interval needed to reduce the pressure difference to 1/2.72 of its initial value) were stipulated as follows:

Instrument tank/LPV :	minimum 8 hours
LPV/free atmosphere :	" 1 hour

APPENDIX 5

NOTES ON THE CALIBRATION OF THE SP AND LP SYSTEMS

A5.1 Calibration of SP seismometers

The seismic sensor is considered to be a pure second order dynamic system, and will as such be fully described by three parameters:

a) natural frequency (f_n)

b) relative damping $h = \lambda / \lambda_{crit}$

c) sensitivity

The first two are well defined and are represented by single numbers. The sensitivity is anyway a function of frequency, and the type of function will depend upon the input. The input, considered as a function of frequency, may be acceleration (force), velocity, or displacement. All calibration operations in the field are carried out with force input, the force being proportional to the voltage impressed on the calibration circuit. The output/input voltage ratio will be a symmetric function of the logarithm of normalized frequency $x = f/f_n$

$$e_{out}/e_{in} = jkx/(1 - x^2 + 2\,jhx)$$

and by comparing the plot with a set of templates of the function above for different values of h, the values for k, h and f_n can be extracted. On this plot we can draw lines of constant sensitivity s. We define sensitivity as the ratio of output voltage e_{out} to displacement d

$$s = e_{out}/d$$

Displacement is expressible in terms of the circuit parameters of the calibration circuit.

$$\begin{aligned} d &= a/\omega^2 \\ &= e_{in}\, G_c/(R_c\, m\omega^2) \end{aligned}$$

where
- a - acceleration of the mass
- G_c - calibration coil motor constant (0.0326 N/A)
- R_c - resistance in cal circuit (50 kohms)
- m - seismometer mass (0.825 kg)
- ω - $2\pi f$
- e_{in} - input voltage (20 volts p-p)

By combining the two equations, we get

$$\begin{aligned} e_{out} &= s\, e_{in}\, G_c/(R_c\, m\omega^2) \\ &= 0.4\, s/f^2 \text{ when } s \text{ is in mV/nm} \end{aligned}$$

The net of constant sensitivity lines will thus consist of straight lines with slope -2 in the logarithmic plot.

It is to be noted that in drawing the lines of constant sensitivity, only parameters of components in the calibration circuit are used.

Any calibration depends on the constancy and correct values of these parameters, no additional approximations or inaccuracies are introduced or accounted for. Sensitivity can now be read directly as a function of frequency from the original plot.

A5.2 SP natural frequency measurements

Capacitance in the cable between the CTV and the WHV may amount to 0.5 μF for the longest cables, and is equal to a capacitive reactance:

$$X_c = 1/j\omega C = 300 \text{ kohm} \quad \text{at } 1 \text{ Hz}$$

Direct measurement of the resonant frequency by the method described in Seismometer Evaluation Procedure, Short Period Vertical Seismometer, LMC-PI MIT Lincoln Laboratory, 9 May 1967, will not be accurate unless all measuring instruments are brought out to the WHV, which is rather impracticable under winter conditions.

In the check-out of NORSAR instruments, a Lissajou comparison of phase between the calibration signal and the output signal through the amplifier has been done, after first compensating for the phase shift of the amplifier.

The phase shift of the amplifier is due mainly to the low frequency cut off, and the transfer function of the amplifier is

$$T_A = A/(1 - j\omega_o/k\omega_o)$$

where ω_o/k - the low frequency 3 dB point

ω_o - the natural frequency of the seismometer

With a compensating network consisting of a series adjustable resistor and a shunt capacitance connected to the output of the amplifier, the response will be

$$T = 1/(1 + jn\omega/\omega_o) \cdot T_A = \frac{A}{(1 + jn\omega/\omega_o) \cdot (1 - j\omega_o/k\omega)}$$

where $n\omega_o$ - the (variable) high frequency cut off of the network

The resultant phase shift will be zero for

$$n\omega/\omega_o = \omega_o/k \text{ , or}$$

$$n = k \text{ for } \omega = \omega_o$$

The natural frequency is not known in advance and successive adjustments may be necessary, but the procedure converges rapidly. The amplifier is first compensated in the cal amp mode. It is essential that a balanced calibration signal is used, or a phase error will arise from the common mode response of the RA-5 amplifier.

The method described above has been compared with the conventional way for seismometers with short cables and the agreement is excellent.

A5. 3 Expected calibration output voltage

The expected output voltage is expressed

$$E_{out} = vG_D D_D A D_T/2h$$

where $v = \omega_n d = 2\pi \cdot 1 \cdot 0.4 = 2.51$ μm/s, is the p-p ground velocity corresponding to the calibration force excitation.

$h = 0.7$ is the relative damping

$v/2h = 2.51/1.4 = 1.79$ μm/s, is the velocity of the mass relative to ground

G_D = 1020 Vs/m, is the Data Coil Generator Constant

D_D = 240/290 = 0.826 (-1.68 dB), is the attenuation caused by the voltage drop in the internal impedance of the data coil when loaded with the damping network.

A = 7070 (77 dB) is the amplification

D_T = 10/(10.5+r), when r is the resistance of the cable loop in kiloohms.

With D_T = 0.935, corresponding to 3.7 km cable and the other values inserted above

$$E_{out} = 10.0 \text{ V}$$

A5.4 SP system sensitivity

The saturation level of the RA-5 amplifier is 14 V p-p. If a reasonable margin against distortion is assumed to be 1.4 to 1, the calibration level will correspond to full output of the analog to digital converter.

Saturation will thus correspond to

400 nanometers earth motion at 1 Hz
10 V at RA-5 and LTSPA (line terminating amplifier)
2 x 8192 quantum units at ADC.

This results in sensitivity:

25 mV/nm	40 nm/volt
0.0244 nm/qu	41 qu/nm
0.61 mV/qu	1.64 qu/mV

The sensitivity in mV/nm is only adjustable by varying the gain of the RA-5. This may be increased by 3 dB from 7070 to 10 000, and may be reduced by any amount by inserting an attenuator in front of the amplifier.

The sensitivity in qu/nm may be adjusted by setting the gain of the line terminating amplifier. This amplifier has variable gain range from 0.357 to 1.43, but with gain settings lower than 0.7 it will not be possible to saturate the analog to digital converter and the practical gain range will be from 0.7 to 1.43.

With the margin that has been chosen against ove ɔad of the RA-5 amplifier, we will thus be midrange of the practical adjustment range of the line terminating amplifier.

In Table A5.1 gain settings of the line terminating amplifier, maximum output voltage of the RA-5 amplifier, and the resulting sensitivity and saturation earth movement are presented for comparison. The gain settings should not be chosen too close to the +0 and +6 dB as this will impose closer tolerances on other parts of the system. If such values are desired, the sensitivity in mV/nm should be adjusted on the RA-5.

Sensitivity qu/nm	Saturation nm at 1 Hz	RA-5 outp volts	LTSPA gain x) (dB)
30	545	13.6	1.025 (0.20)
32	512	12.7	1.09 (0.80)
34	482	12.0	1.16 (1.30)
36	455	11.4	1.23 (1.80)
38	432	10.8	1.30 (2.40)
41	400	10.0	1.40 (2.40)
45	365	9.1	1.54 (3.7)
50	328	8.2	1.71 (4.6)
55	298	7.5	1.88 (5.5)
60	274	6.9	2.04 (6.2)

x) A fixed attenuation 5/7 is inserted between RA-5 and LTSPA and a gain 7/5 = 1.4 will give the same voltage at RA-5 output and the multiplexer.

Table A5.1 Sensitivity, saturation level of earth movement, maximum voltage from RA-5, and LTSPA gain setting

A5.5 LP calibration

The essential initial calibration of the LP seismometer consists in equalising a deflection caused by a 100 mg weight acting on the center of gravity of the moving system with the deflection caused by a current 35 mA through the calibration circuit.

This amounts to standardising the effective motor constant of the calibration coil to

$$G_c = 0.0280 \text{ N/A}$$

since $G_c \cdot I = 0.028$ N/A x 0.035 A = 0.000980 N, which is exactly the force exerted by the 100 milligram,weight.

This calibration is performed at the installation of the seismometers. In the case of the vertical seismometers, the weight is placed directly on the boom at an index provided for that purpose. When horizontal seismometer is calibrated, the force is created by a v-suspension of greater weight closer to the fulcum, the force being equivalent when lever ratios are taken into consideration.

Seismometers are also checked with respect to generator constant which nominally should be 750 Vs/m. The generator constant is equal to the motor constant, both being equal to the product $B_m \cdot l$ where B_m is the mean induction and l is the total length of the coil wire cutting the flux.

For convenience a current is chosen that deflects the weight the same amount as one hundred milligrams would do in the center of gravity of the moving system. This cur-current is 1.31 μA since

$$F = G_D \cdot i = 750 \cdot 1.31 \cdot 10^{-6} = 0.00098 \text{ N}$$

Finally the damping is checked and adjusted to $0.64\,\lambda_o$ where λ_o is critical damping. This corresponds to an amplitude ratio 13.7 to 1 between successive peaks.

In the operational calibration a 450 μA p-p current is passed through the calibration circuit exerting a force $G_c \cdot i$ on the moving system.

The earth displacement that produces the same response is expressed by

$$d = G_c i/(m\omega^2)$$

where G_c = 0.0280 N/A is the motor constant of the calibration circuit

i = 450 μA

m = 10 kg, the mass of the moving system

ω - the frequency of the calibration signal

The output voltage is expressed by

$$E_{out} = vG_DA$$

where $v = \omega_n d\, x^3/(1 - x^2 + 2hjx)$ is the velocity response of the moving system when the input d is constant with frequency

$x = f/f_o$

$h = \lambda/\lambda_o$

G_D = 750 Vs/m is the data coil generator constant

A = A(x), the amplification of the Ithaco amplifier, is a function of frequency

The sensitivity is defined by

$$S = E_{out}/d = \omega_n G_D \cdot A(x) \cdot E(x)$$

with $E(x) = x^3/(\mu - x^2 + 2jhx)$

T(s)	x	E(x)	A(x)	S mV/μm
10	2	2.02	200	96
16	1.25	1.15	1150	315
20	1.0	0.780	2500	464
22.5	0.89	0.608	3200	464
25	0.80	0.470	4000	448
30	0.667	0.287	6000	339
50	0.40	0.065	9600	149
100	0.20	0.008	9700	19

Table A5.2 The LP system sensitivity as a function of the period T of the sinusoidal movement ($f_o = \frac{1}{20}$)

The output voltage at the calibration frequency $f = 0.04$ (which with the Ithaco amplifier characteristic is not the frequency of maximum sensitivity) will be

$$E_{out} = S \cdot d$$
$$= 0.450 \text{ V}/\mu\text{m} \times 20\,\mu\text{m} = 9.0 \text{ V}$$

The amplifier is thus able to handle earth movements before overload

$$d_{max} = \frac{60}{9} \cdot 20\,\mu\text{m} = 133\ \mu\text{m}$$

or if 1.33 is taken as a reasonable margin against overload

$$d_{FS} = 100\ \mu\text{m}$$

at $E_{FS} = 45$ V (FS -Full Scale)

This requires a 45/10 = 4.5 = 13 dB attenuator between the output of the amplifier and the input of the multiplexer, and the sensitivity will be

164 qu/μm

61 nm/qu

The calibrating level will thus be at 1/5 of Full Scale.

When calibrating the amplifier with 4 mV at 25" period (f = 0.04), where the gain is 4000, the output voltage will be 16 V.

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13 ABSTRACT

Project NORSAR concerns installation and operation of a large seismic array in S-E Norway.

This report covers that part of the NORSAR Phase 2 installation which has customary been entitled the 1968 Installation Program. It covers the field installations of the so-called A and B-ring subarrays, i e the innermost 8 subarrays of the array, and to some extent also the establishing of the Data Processing Center at Kjeller and the telecommunication channels linking the latter to the individual subarrays.

Various circumstances made it necessary that the 1968 Installation Program was extended in time well beyond the calendar year 1968. The period covered by this contract expires late spring 1969.

KEY WORDS

NORSAR - Norwegian Seismic Array
Norway - Large Aperture Seismic Array
Large Aperture Seismic Array
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Seismic Signals Processing
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